BRITISH AEROSPACE (MILITARY AIRCRAFT) LIMITED
WARTON AERODROME
PRESTON, LANCS
PR4 1AX

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TITLE: BAe - University Round Table on Gravitational Research

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APPROVED

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Mr. T.R. King
(Head of Future Business Strategy)

BRITISH AEROSPACE

Report on Meeting held at the NOVOTEL Conference Centre, Preston on Mon/Tues 26/27 March 1990.

The Meeting was unclassified and completely open.

Summary

A 2-day BAe-University Round Table on Gravitational Research was held during 26 & 27 March 1990. This report largely gives the author's view of the proceedings but includes many viewgraphs of the presenters.

The objective of this meeting was to learn, to identify any potential areas of breakthrough that could have a dramatic effect on MAL future business and single out any business opportunities.

The first day was spent discussing current research projects, including Gravitational Wave Astronomy, Gravity Gradiometry and 5th Force experiments.

The second day dealt with speculative ideas about gravitation, including microgravity research, the Heavisidian field, a relativistic wave model of the electron and an experiment which might detect a link between the gravitational constant G, the permittivity ε and the permeability μ of free space.

The Round Table Meeting was judged as a success by BAe. It has signalled BAe's awakening interest in gravitational physics to the scientific community and given us first hand information about some of the ongoing research work.

Distribution

Conference attendees.

BAe HQ Strand

Mr. G.J. Felton

BAe HQ Farnborough

Dr. A. Clementson

BAe Sowerby Research Centre

Mr. D. Hitchings

BAe MAL

Mr. B. Young
Mr. M. Mansell
Mr. T.R. King
Library

List of Attendees

1. Mr J Ackroyd (0272-693831)
University Liaison & Resources Manager
BAe (Sowerby Research Centre)
PO Box 5
Filton
Bristol
BS12 7QW

2. Mr I Butchart (0772-201201)
Dept. of Physics & Astronomy
Lancashire Polytechnic
Preston
PR1 2TQ

3. Mr A Carmichael (041-339 8855)
Dept. of Physics & Astronomy
Glasgow University
Glasgow

4. Dr A M Cruise (0235-821900) Ext. 6675
Dept. of Space Studies
Rutherford Appleton Laboratory
Chilton
Didcot
Oxfordshire
OX11 0QX

5. Prof G Donaldson (041-552 4400 Ext. 3367)
Dept. of Applied Physics
University of Strathclyde
187 Rotten Row
Strathclyde
G4 0NG

6. Mr M Gross (091 232 8511)
University of Newcastle
Newcastle
NE2 4BW

7. Dr P A Hansson (01-840 1082)
Commercial Space Technologies
67 Shakespeare Road
London
W7 1LU

8. Mr R M Hill (091-222-7346)
Dept. of Physics
University of Newcastle
Newcastle
NE1 7RU

9. Mr M Hosey (041-552 4400 Ext. 3478)
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University of Strathclyde
187 Rotten Row
Strathclyde
G4 ONG

10. Prof R C Jennison (0227 764000)
Dept. of Physical Electronics & Radio Astronomy
University of Kent
Canterbury
CT2 7NT

11. Mr E Morrison (041-339 8855)
Dept. of Physics & Astronomy
Glasgow University
Glasgow

12. Dr A Wright (0272 693831)
BAe (Sowerby Research Centre)
FPC 267
PO Box 5
Filton
Bristol
BS12 7QW

Attending from BAe (Military Aircraft) Ltd

13. Dr R A Evans (Chairman)

14. Mr G Salkeld

15. Mr G R Seyfang

PROGRAMME

1st Day	12.30pm	Arrival and Buffet Lunch
	2.00pm - 2.10pm	Introduction Dr R A Evans (BAe MAL)
	2.10pm - 2.30pm	The Sowerby Research Centre & University liaison. Mr J Ackroyd (BAe SRC)
	2.30pm - 2.45pm	BAe overview of current Gravitational Research Dr R A Evans (BAe MAL)
	2.45pm - 3.45pm	Gravitational Wave Research Mr A Carmichael & Mr E Morrison (Univ. Glasgow)
	3.45pm - 4.00pm	Tea
	4.00pm - 5.00pm	Fifth Force experiments Mr M Gross & Mr M Hill (Univ. Newcastle)
	5.00pm - 6.00pm	A superconducting Gravity Gradiometer Mr M Hosey (Univ. Strathclyde)
	7.00pm	Dinner
2nd Day	9.30am - 9.45am	A reminder of Faraday's Gravitational experiments Dr R A Evans (BAe MAL)
	9.45am - 10.45am	Microgravity Dr P A Hannson (Commercial Space Technologies)
	10.45am - 11.00am	Heaviside's linearised gravitational theory Dr R A Evans (BAe MAL)
	11.00am - 11.15am	Coffee Break
	11.15am - 12.45pm	A new model of the electron. Prof R C Jennison (Univ. Kent) A suggested experiment to search for a link between electromagnetism and gravity. Prof R C Jennison
	12.45pm - 12.50pm	Brief Round-Up.
	1.00pm	Buffet Lunch

Introduction

BAe is one of Britain's largest manufacturing group of companies, employing more than 130,000 people. The turnover last year was £9 billion, of which nearly £5.4 was in overseas sales. In these days of diversification it would be wrong to think that BAe is primarily engaged in military projects, although defence still forms a large part of the business.

We are a relatively new public company, having been privatised in 1981. But already, as you can see (Slide 1), we have achieved international status and are engaged in a variety of activities.

Looking briefly at the Corporate Structure (Slide 2), we have Professor Roland Smith, (UMIST) as the Chairman of the Board of Directors.

This meeting is held under the auspices of BAe (Military Aircraft Ltd) and BAe (Sowerby Research Centre).

Military Aircraft Ltd (MAL) is wholly owned subsidiary of BAe with a large degree of independence from the main board. MAL is made up from the following 8 sites (SLIDE 3) Brough, Dunsfold, Hamble, Kingston, Preston, Samlesbury, Warton and Weybridge. Warton (SLIDE 4) is the H.Q. site for MAL.

The idea for a conference on gravitational research began in the Future Business Strategy Department (FBS) at Warton. This is a new department, staffed mostly with engineers from the future Concepts Department. FBS has retained a role in new concept initiation, has the important task of assisting in the formulation of future business strategy for Senior Management, including the identification of any potential developments that could have major long term impact on MAL business. Furthermore, it shares in the monitoring task of ensuring that the MAL R&D programme is consistent with the agreed business strategy.

Now I'm not permitted to tell you how many millions of pounds is spent on R&D by MAL, but a recent article in the Financial Times (28th Feb. 1990) will give you an idea. Mr Ivan Yates, the Chief Executive (Engineering) at BAe HQ in London and a former Managing Director at Warton, was interviewed last month about BAe's corporate R&D policy (Slide 5).

In 1989 BAe spent about £600 million on Research & Technology.
As you will appreciate, Aerospace design provides a focus for advanced technology and therefore does require a large amount of Research & Development work.

For an aerospace company to survive in the hard commercial world of exploiting technology it must remain at the forefront of technological understanding. This does not mean just Test & Development but genuine research work.

Some of this work is carried out for BAe in Universities and this seems likely to increase.

BAe has also set up the Sowerby Research Centre (SRC), near Bristol in order to concentrate on longer term research work.

Within MAL, R&D is generally aimed at near term (say 5 years) technologies to assist current programmes. However, via (FBS), a small amount of 'blue-sky' (say 15 years hence) research will continue at MAL in order to aid future concept ideas.

It is under this flag that we meet today.

GROUP COMPANIES AND INVESTMENTS

as at 15th March, 1989

BALLAST NEDAM BV

Ballast Nedam Groep NV
Ballast Nedam Construction International BV
Ballast Nedam International BV
Ballast Nedam Bouw BV (Civil Engineering)
Ballast Nedam Handel & Industrie BV (Manufacturing & Trading)
Amsterdamse Ballast Bagger en Grond BV (Amsterdam Ballast Dredging)
Ballast Nedam Engineering BV
North American Trailing Company Inc (20%)

BRITISH AEROSPACE (COMMERCIAL AIRCRAFT) LIMITED

Airbus Industrie (20%) (GIE)

BRITISH AEROSPACE (CONSULTANCY SERVICES) LIMITED

BRITISH AEROSPACE (DYNAMICS) LIMITED

Euromissile Dynamics Group (33⅓%) (GIE)

BRITISH AEROSPACE ENTERPRISES LIMITED

Aerostructures Hamble Limited
Arab British Dynamics Limited (30%)
AWA Micro Electronics Pty Limited (25%)
British Aerospace Australia Limited
British Aerospace Flying College Limited
British Aerospace Simulation Limited
Competence Center Informatik GmbH (30%)
SD - Scicon plc (23%)
Singapore British Engineering Pte Limited (49%)
Steinheil Optronik GmbH
Wind Energy Group Limited (50%)

BRITISH AEROSPACE HOLDINGS INC

Arkansas Modification Center Inc
Austin Rover Cars of North America Inc
Austin Rover USA Inc
British Aerospace Inc
British Aerospace Finance Inc
Jet Acceptance Corporation
Range Rover of North America Inc
Reflectone Inc (38%)
Rover Group USA Inc
Royal Ordnance Inc
US Wind Energy Group Inc (33⅓%)

BRITISH AEROSPACE (MILITARY AIRCRAFT) LIMITED

Panavia GmbH (42.5%)
Eurofighter Jagdflugzeug GmbH (33%)

BRITISH AEROSPACE (SPACE SYSTEMS) LIMITED

British Aerospace Telecommunications Limited
Satcom International (50%) (GIE)

BRITISH SCANDINAVIAN AVIATION AB

THE ROVER GROUP PLC

Austin Rover Finance Limited (20%)
Austin Rover Group Limited
DAF BV (40%)
Istel Holdings Limited (25%)
JRA Holdings Limited (20%)
Land Rover UK Limited
UGC Limited (22%)

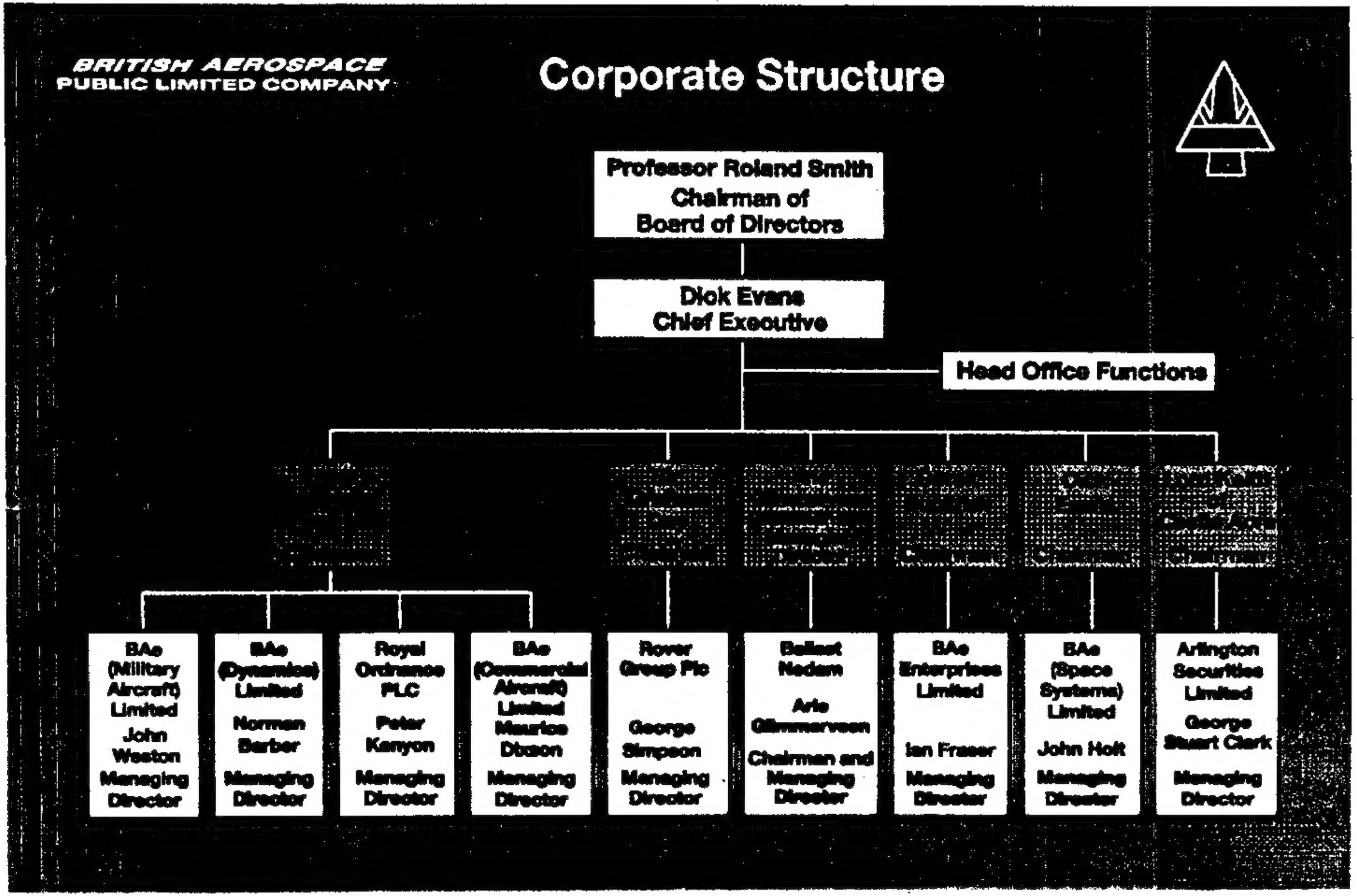
ROYAL ORDNANCE PLC

Royal Ordnance Speciality Metals Limited (85%)

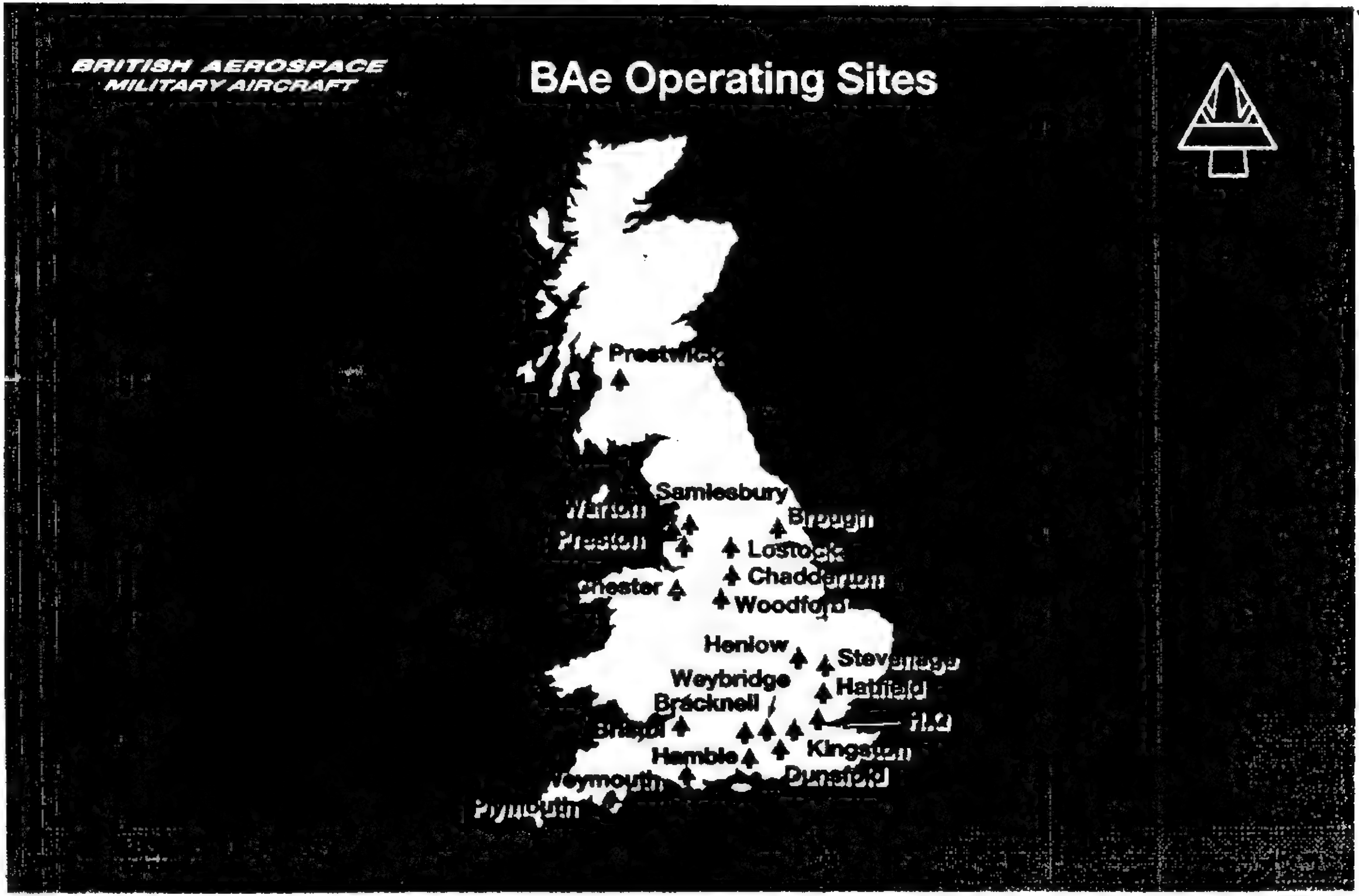
TRAFALGAR BROOKMOUNT (BROOKLANDS) LIMITED (50%)

Arlington Securities Ltd.

SLIDE 1


BRITISH AEROSPACE
PUBLIC LIMITED COMPANY
Corporate Structure
Professor Roland Smith Chairman of Board of Directors
Dick Evans Chief Executive
Head Office Functions
BAe (Military Aircraft) Limited John Weston Managing Director
BAe (Dynamics) Limited Norman Barber Managing Director
Royal Ordnance PLC Peter Kenyon Managing Director
BAe (Commercial Aircraft) Limited Maurice Dixon Managing Director
Rover Group Plc George Simpson Managing Director
Ballast Nedam Arie Glimmerveen Chairman and Managing Director
BAe Enterprises Limited Ian Fraser Managing Director
BAe (Space Systems) Limited John Holt Managing Director
Arlington Securities Limited George Stuart Clark Managing Director

SLIDE 2


BRITISH AEROSPACE
MILITARY AIRCRAFT
BAe Operating Sites
Prestwick
Samlesbury
Warton
Brough
Preston
Lostock
Chadderton
Woodford
Henlow
Weybridge
Hatfield
Bracknell
Hamble
Kingston
Dunsfold
Plymouth

SLIDE 3

WARTON

Warton Aerodrome, Preston, Lancashire, PR4 1AX

Tel: (0772) 633333

- Military Aircraft Division Management Centre
- Administrative centre for Warton - Preston - Samlesbury Unit
- Principal Product responsibilities:
  - EAP/Eurofighter
  - Tornado
  - Jaguar
  - Strikemaster
  - Lightning
  - Canberra
- Defence support services
- Principal resources:
  - Divisional Wind Tunnel Testing Facilities
  - Research
  - Design
  - Development
  - Final assembly
  - Flight testing & despatch
  - Service department
  - Return to works programmes
- 6,580 employees (including 221 overseas support personnel based at Warton)
- 1.6 million sq. ft. factory floor.

SLIDE 4

In the first of two articles about BAe's research and development, **David Fishlock** explains how the company integrates a score of technologies

Military imperatives set a flying pace

Ivan Yates: responsible for BAe's technical health

No British company spends more on research and technology than British Aerospace - about £600m last year compared with £400m for ICI. But the comparison should probably stop there, so different are their situations.

Chemicals industry R&D aims to find a new product, to treat heart disease for instance, or a new way of making a commodity such as ammonia. But a new aircraft, such as the European Fighter Aircraft, involves the integration of up to 20 technologies.

Even though any one of them may be less complex than a chemical process, a score of technologies under development simultaneously can be a nightmare, says Ivan Yates, BAe's chief executive (engineering) since 1986. "When you start putting an aeroplane into production you go through an appalling period."

This conjunction of so many technologies means it is not always obvious what is happening. A failure or accident, for example, can sometimes be explained in several ways.

BAe's products range in complexity from the £18m Tornado warplane with 500,000 components, a fifth of them unique to the aircraft, to the Rover car with a mere 50,000 parts.

Fashion is the dominant factor driving car technology, Yates says. Rover does not create new technology but picks up ideas in combustion, emission control, materials and so on, and adapts them. Much of its R&D has traditionally been done by suppliers. It aims to know how to make the complete vehicle, but only in order to be an informed customer in selecting which parts it will make and which it will buy.

Rover, says Yates, does development rather than research, a policy that has not changed since BAe took it over. Steps are being taken to put Rover in contact with BAe's technology base "but it will take time," says John Arnall, BAe's head of R&D.

Aircraft technology is driven by other imperatives, performance and safety particularly. Until the 1970s the innovations were made on military aircraft and the industry sought "spin-offs" in the civil sector. But a drive for greater efficiency has put the civil sector ahead in some important facets of technology, notably wing design, which is closer to the limits of physics in the Airbus than in military aircraft.

Nevertheless, military imperatives still set the pace in many areas of performance. Four examples of this, which Yates reckons will all be transferred to the civil sector, are:

BRITISH AEROSPACE

fly-by-wire controls, in which the computer takes charge of engines, control surfaces, etc; lightweight carbon fibre structures, such as wings and potentially the entire fuselage; integrated digital avionics, in which all the aircraft's "black boxes" are part of a common management system; and inherent instability, or designing for the best performance without being constrained by the aircraft's stability.

All four feature in a demonstrator aircraft called the EAP, standing for experimental aircraft programme, a progenitor of the European Fighter Aircraft. The EAP - there is but one - is based at BAe's military aircraft headquarters at Warton, Lancashire. Mike Mansell, the division's director of technology, says "It's so unstable, you can't fly it without computers."

A programme of high-agility test flights has demonstrated that the pilot can be "as rough as he likes," says Mansell. It has also shown that all four technologies, vital to the next generation of warplanes, will work in concert.

Inherent instability will give military aircraft an agility they cannot aspire to at present. But Yates believes the technology will spin off into civil aircraft, for instance in coaxing a faster and smoother response to sudden atmospheric disturbances, such as wind gusts, than any airline pilot could manage. "He'd respond too late and make things worse," Yates says. It could mean a better ride for the passenger and less stress for the airframe.

The team of 600 working for Mansell at Warton is expected to expand to 900 this year. Arnall says the company wants to use the well tried technology management practices of Warton - its biggest R&D activity - as a corporate standard.

It is misleading to think that BAe spends £600m a year on innovation. Yates reckons that only about £250m meets the widely used Frascati definition of R&D, which stipulates that there must be a significant degree of innovation. Of this £250m, about £80m comes from company profits and the balance from overheads and contract R&D.

Yates prefers to call much of the other £350m "defence engineering." It usually consists of testing for the Ministry of Defence, including flight testing not just of new systems but of subsequent modifications. Yates estimates that as little as 10 to 15 per cent of BAe's R&D for the ministry has an innovative content.

BAe also spends about £4.25m on research contracts with the universities. In 1981, The company responded to what it perceived as a wider trend to cut spending at the research end of the R&D spectrum by setting up a central laboratory, called the Sowerby Research Centre, at Filton near Bristol.

Several BAe business units work closely with Sowerby, not only contributing to its £14m budget but also placing research contracts with it, and using its scientific instruments for their own research. Sowerby is no ivory tower but an integral part of BAe technology. It has even produced its first commercial spin-off, a wholly owned BAe company specialising in lasers as manufacturing systems.

Each BAe business, including civil aircraft, military aircraft, weapons and electronic systems, Royal Ordnance and Rover, has a business plan which includes its spending on R&D. The Technical Policy Committee - composed of technical directors from the businesses, along with Yates - weighs whether the plans allocate enough to technology to meet commercial objectives, as well as analysing interaction between the concerns to form a corporate over-view of BAe technology.

The committee asks such questions as whether a business can afford - or can afford not - to invest in a key technology.

The plans then go into the chief executive review, where Yates sits as R&D champion. Such a technical appraisal has been made by the aircraft side of the company for a decade but has only recently become a corporate matter. For Rover, it has been raising such issues as the possible use of BAe's carbon-fibre component technology, and its understanding of the man-machine interface for future car design.

Arnall also studies the plans to see whether the company is leaving technology gaps. Should he find any, it falls to Yates to fill them. Since Yates has no "pot of gold" of his own, he must do this by twisting the arms of fellow directors.

Yates's constant worry is that Britain is not spending enough on aerospace technology to maintain its international standing. Where BAe differs from, say, ICI is that it has always been able to draw heavily on the world aerospace community because the UK has contributed generously to its R&D base, both through its companies and through national laboratories such as the Royal Aerospace Establishment, Farnborough.

But Government funding is steadily falling, he says. "I'm concerned that other countries are continuing to fund their aerospace industries as a matter of national strategy. Our Government is pulling out."

The second piece on BAe's approach to R&D, focusing on central research, will appear next week.

SLIDE 5

The Sowerby Research Centre & University Liaison

Introduction to Sowerby Research Centre

In any active high technology industry there is always the problem of deflecting staff studying long term problems to solve immediate difficulties. Jim Sowerby, as Director of Engineering for the British Aerospace Dynamics Group approached this problem by centralising the research type activities in one location. The organisation of the Group at the time essentially divided it into two units, at Stevenage and Bristol. The separation was such that the centralised research at Bristol was insulated from the unfortunate distractions of 'Fire Engine' problems but not isolated from playing a proper part in resolving serious difficulties nor ensuring relevance for the long term enabling studies forming the main programme.

Following a major re-shaping of British Aerospace it was decided to extend the role of the Research Centre to fulfil the same function for the whole of the British Aerospace Companies. It was funded by a levy on all the groups and to ensure an overall balanced approach on technical matters, reported to Headquarters via the Corporate Technical Director. This is still the case and now the aim is to support the even wider range of BAe companies. The role of this support is to provide forward research on enabling technologies to give a sound background for the engineers and designers.

At present there are about 200 scientists and engineers grouped broadly by discipline into Departments. Financial support is provided by attributions from the companies and controlled by a Management Committee that includes representatives from the Operating Companies. The technical programme is outlined in a Five Year Plan revised annually and discussed with the Operating Companies for relevance to the overall needs. The programme is then controlled by technical areas, to ensure an integrated approach, across all sources of research.

The Links with Universities

It is clear that 200 scientists cannot cover all our research needs. In fact almost half of the research is done outside the Centre, some of it in the Operating Companies. The close scrutiny of the technical area managers working from the Centre alleviates the original distraction problem.

Another very important research resource is the use of Higher Education Institutes. They have several roles in the interaction.

A source of recruits
Specialist consultancy on specific problems
Long term research
Research into fundamentals.

The last two are of particular importance for this seminar.

The links with Higher Education Institutes start at a local level and there are many interactions at all sites. These range from supporting CASE students through particular research contracts to supporting chairs in relevant disciplines. The total sum involved is about £M3.5 per year. The particular geographic distribution of BAe companies makes it appropriate to consider extending these local links to cover regions. Such an arrangement exists with the Northwest Consortium of Industries and universities comprising:-

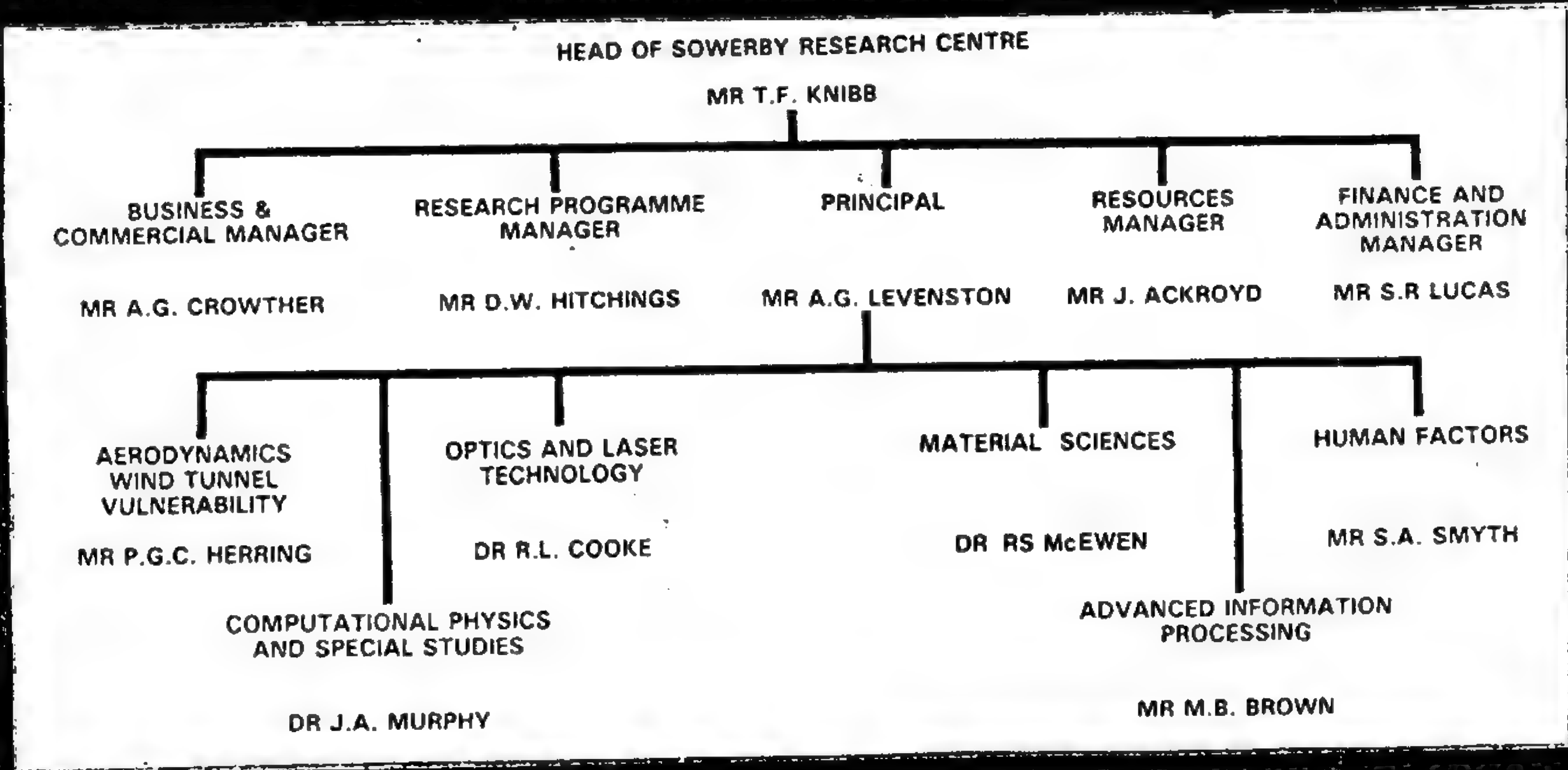
BAe (Warton)	Lancashire Polytechnic
Unilever	Manchester University
Ciba Geigy	UMIST
ICL	Liverpool University
ICI	Salford University
Pilkington	

A similar approach is being considered for the Southwest centred around the BAe Bristol site.

In addition to this regional approach there is the recognition that there are Centres of Excellence where the nature of the capability is such that distance is no object. There is also the fact that although in some cases the universities are an alternative resource to BAe facilities there are others where they are clearly the most appropriate choice. In fact they may be the only choice. Fundamental studies to elicit basic understanding is one such case. Speculative studies where the immediate implementation of the knowledge gained is not obvious may be another.

J ACKROYD

Sowerby Research Centre



DBL/RRC 10690 B/02

BAe Overview of current Gravitational Physics Research

Gravitational Physics is a subject that the public generally associates with you, the academics, with your heads in the clouds. So why is British Aerospace interested in Gravitation?

Need I remind you that BAe (MAL) products are designed to defy gravity and that the clouds are part of the realm of these machines. What is more, the sky is not the limit. We are very interested in Space too. At Warton, we've had a team working on HOTOL, a single stage rocket launcher, for several years.

The Engineers at BAe, who turn today's future concepts into tomorrow's aerospace machines, are acutely aware of the fierce, worldwide competition. To stay up with the leaders means that we must keep an eagle eye on emerging technologies, ready to swoop down when any new business opportunities present themselves.

At MAL, the Future Business Strategy Dept has been allocated a small amount of money to spend, speculatively, on any new areas of technology which we feel might blossom over the next 15 years, or so.

Over the last few years we've noticed an increasing tempo in the field of gravitational physics. There's more funding available (as indicated by the absence of Professors Hough and Schutz), there's more TV time devoted to the subject, more books and articles in the press too.

Two advertisements have recently caught my eye. The first (Slide 1) is by the Central Electricity Generating Board. Within 5 years of Faraday's discovery of electro-magnetic induction, the electric motor industry began. Within 70 years, generating electricity was big business. Faraday had no idea what his new born baby would turn into, but he was sure that the politicians would tax the adult. Even so, it's provided a bonanza. What is noticeable today is that the period between discovery, invention and marketing is getting shorter and shorter. This is especially true in the field of electronics and those fields related to it.

The second advertisement (Slide 2) contained a picture of Einstein. The scientific community are seeking a breakthrough in gravitational physics and The Business World, with its venture capital, is fascinated by the prospect. When the breakthrough occurs it is bound to have an impact on aerospace business, but if BAe are 'insiders' we can benefit.

Now we might be premature, but we would like an update from the experts on where you are at the present with your research and where it is leading. We are also looking for areas of research which we might fund in order to nudge them along. In particular, we are looking for some speculative experiments which might possibly demonstrate a link between electromagnetism and gravity. We hope to discuss the merits, or otherwise, of any experiments proposed during the round-table meeting. Being realistic, we accept that no experimental ideas may have survived by the end of the meeting, however, in the process we should have learnt enough to allow us to make a judgement for our future research policy in this area.

I thought that to get the meeting really into the swing of gravitational physics I'd start with a series of montages covering what we perceive to be the main areas of activity. Then it's over to you.

Let's start with Gravitational Wave Telescopes (Slide 3). We know that Professor Hough and Professor Schutz are currently attending an SERC meeting to discuss the building of a European Gravitational Wave Telescope. Funds of £30 million are being talked about. The US is also very active here, with both resonant bar and interferometry methods of detecting gravitational waves being developed. Japan and Australia are also entering the scene.

At the moment, BAe's only input is the supply of small mirrors for the laser system of the Glasgow University gravitational interferometer.

Can we learn any more? Can we earn any more? Alan Carmichael and Euan Morrison will tell us more, in a little while.

Most engineers within BAe know about the 4 fundamental forces of the Universe. During 1988 and 89 there was a hive of activity concerning a possible 5th force (Slide 4). Fischbach claimed that the original Von Eötvös balance results had been misinterpreted. Stacey's measurements down a Queensland mine apparently confirmed that there was a short range (5th) force associated with the composition of a body. TV science programmes showed various experiments performed, to try to measure this force. Perhaps there was a 6th force too?

Later, tests carried out down boreholes in the Greenland Ice Sheet seemed to dismiss the idea of a 5th force. Where are we now?

We've heard that Newcastle University are still interested in the 5th force and that preliminary experiments have been carried out at a reservoir in Wales. Max Hill and Mike Gross will describe the work later on today.

Last year there was a lot of press coverage about CERN and the LEP, the Large Electron Position accelerator, being used to smash electrons. But what is an electron? (Slide 5). Professor Roger Jennison has some ideas.

We've read that protons and neutrons are made up of quarks of different colours. Things seem to have moved on a great deal since we learnt about the Bohr atom. The academic Press are talking about the field quarks, W and Z, the carriers of the weak field force, first discovered in 1984. There is also mention of the Higgs particle which might give mass to all other particles. Can anyone explain this to us in simple terms?

There is speculation by Dr Bob Forward, recently retired from Hughes Aircraft Co., that the molecular Van der Waals, or Casimir, force can be used to extract energy from the vacuum, through fluctuations of the ether. Is this science fiction or should we be paying more attention to these ideas? Perhaps Anders Hansson will tell us more about this subject and give us some advice?

Let's move on to the even more controversial subject of Inertial Drive Machines (Slide 6). Is it possible to convert rotational acceleration into linear acceleration? Professor Laithwaite suggested in 1974 that it might be. Since then a number of inertial thrust machines have been patented.

These include:- The Dean Drive
The Kidd Machine
Scott Strachan's Machine
The Scovellator

Sandy Kidd allowed us to test his machine at Warton, last May. However, we could not detect the 2% change in weight claimed to have been measured by an Australian Laboratory. If it did work, it would be useful in satellite manoeuvring, for which gyros are already used in a different fashion.

This year we offered £10,000 to Professor Salter, at Edinburgh University, to fund the building of a force-measurement rig capable of carrying a variety of devices and intended to resist the large vibrations associated with machines which are claimed to provide inertial thrust. Particular attention will be paid to ensuring that there are no non-linear couplings to ground. Steven Salter's group are heavily involved with the development of anti-vibration equipment for the ESPRIT programme which has to have priority. Time might be available in the first half of 1991 to conduct a series of independently scrutineered trials of inertial drive machines. Professor Salter has published a draft test protocol which has not yet been accepted by any of the inventors of these machines.

Since 1974 Professor Laithwaite has modified his ideas slightly and is now trying to detect inertial radiation between two spinning wheels. This is a relativistic effect which has been considered by Weber and others. Clearly there is an analogue between the magnetic field developed by a current carrying coil and a spinning mass ring. The, as yet, undetected force field surrounding the spinning mass is called the gravito-magnetic field and its existence was predicted as long ago as 1893 by Oliver Heaviside. But even if it exists, it seems likely that it will be too small to measure. Or will it? Only recently two Japanese scientists claimed that a spinning gyro could lose weight, although this was disputed by American scientists who repeated the experiment.

Talking of gyros, consider the hundreds of millions of dollars spent by the US government over the last 20 years on the NASA Gravity Probe B experiment (Slide 7), which contains the World's most perfect gyros.

Gravity Probe B (GP-B) is a satellite, containing a set of 4 perfect gyros, which will be placed in a 650km free-fall polar orbit with the gyro spin axes lying in the plane of the orbit and pointing at a fixed star.

The aim of the experiment is to test Einstein's theory of General Relativity by trying to measure gyro precession caused by space-curvature and gravito-magnetic effects of the rotating earth. This last effect was predicted theoretically by Lense & Thirring and often goes under the name of frame dragging. It is the gravitational analogue for the Lorenz Force of electromagnetic theory. Incredibly, the precessional angle they are trying to measure due to this effect is 0.042 arc sec per year. To attempt such a measurement SQUID (Superconducting Quantum Interference Device) detectors are used. These allow ultra fine measurements to be made and perhaps more mention of these devices will be made by Professor Gordon Donaldson and Mark Hosey.

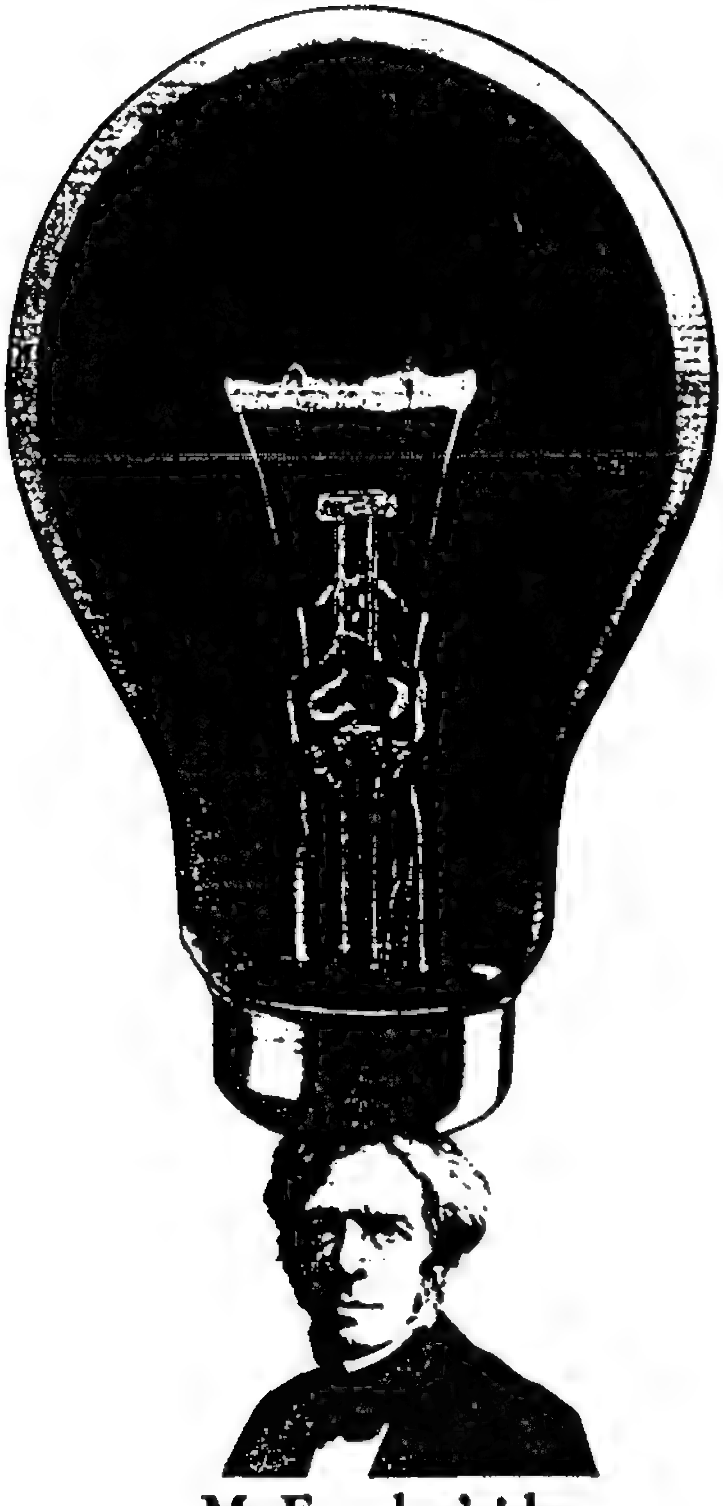
Incidently, the Russians have suggested an alternative, much cheaper experiment, which might be able to detect the gravito-magnetic field of the earth. This involves the use of a Foucault pendulum and sighting telescope at a site near to the South Pole.

Moving on. The Principle of Equivalence states that at any point in Space it is not possible to distinguish between acceleration and gravitational fields. However, over a small distance it is possible to determine the local spatial gradients and from this information we can separate gravitationally induced accelerations from other forms. The devices used to measure the spatial gradients in acceleration fields are called gradiometers (Slide 8). These devices can be mounted on moving vehicles and used to determine the gravitational field of the planet below. There are a number of reasons for wanting to do this. These include geophysical explorations (i.e. search for oil, ore etc) and the improvement of inertial navigation.

A number of different types of gradiometer have been developed. These include the Hughes Aircraft rotating gradiometer, the Draper Lab neutrally bouyant, floated gradiometer and the Bell Aerospace rotating pendulous gradiometer. Bell won a DOD contract to supply a large number of their gradiometers for use in US submarines to improve underwater navigation.

More recently, to improve gradiometer accuracy, attention has been turned to superconducting gravity gradiometers. The UK, the USA and Australia are known to have research programmes ongoing. NASA are planning a satellite mission to carry out a gravity gradiometer study of the earth. In Europe, I understand that ESA are planning a similar study and the French company, Crouzet, will build the gradiometer. No doubt Professor Donaldson and Mark Hosey will tell us more about these programmes and explain to us how the superconducting gravity gradiometer works.

We now look forward to hearing the presentations from the experts.



Mr. Faraday's idea was bigger than he knew.

Making electricity is simple, as Michael Faraday taught us in 1831. If you keep spinning a copper disc inside a magnet, you'll generate a continuous supply.

Generating enough electricity, on the other hand, has created one of the biggest businesses in Britain, with assets of around £25 billion.

Our turnover last year was more than £8 billion, our trading profit £500 million. We still use magnets and copper. But on a massive scale, 24 hours a day, 365 days a year.

And we use good old steam power to turn most of our turbines. But to get up a sufficient head of steam we need a massive fuel supply.

Our annual fuel bill is over £4 billion, more than half our total costs. So keeping fuel costs down is clearly essential for our business.

And for the nation's business. Just about everyone in England and Wales uses our electricity. We have to generate as much as is needed, at as low a price as possible.

So we use many different fuels; fossil and nuclear.

And we'll continue to seek new sources of power: to harness the wind and the tides and the heat beneath the earth's surface.

Our efforts are needed not only to keep prices down, but to satisfy a widely fluctuating demand, day and night, summer and winter; through storms and strikes and other acts of God or man.

That's the generating game: high stakes, tough rules and plenty of challenges. But it's a game we have to go on winning.

By using our magnets, like Mr Faraday said.

THE GENERATING GAME

SLIDE 1

CENTRAL ELECTRICITY GENERATING BOARD

THE FACTOR BEHIND ALL GREAT PERFORMANCE

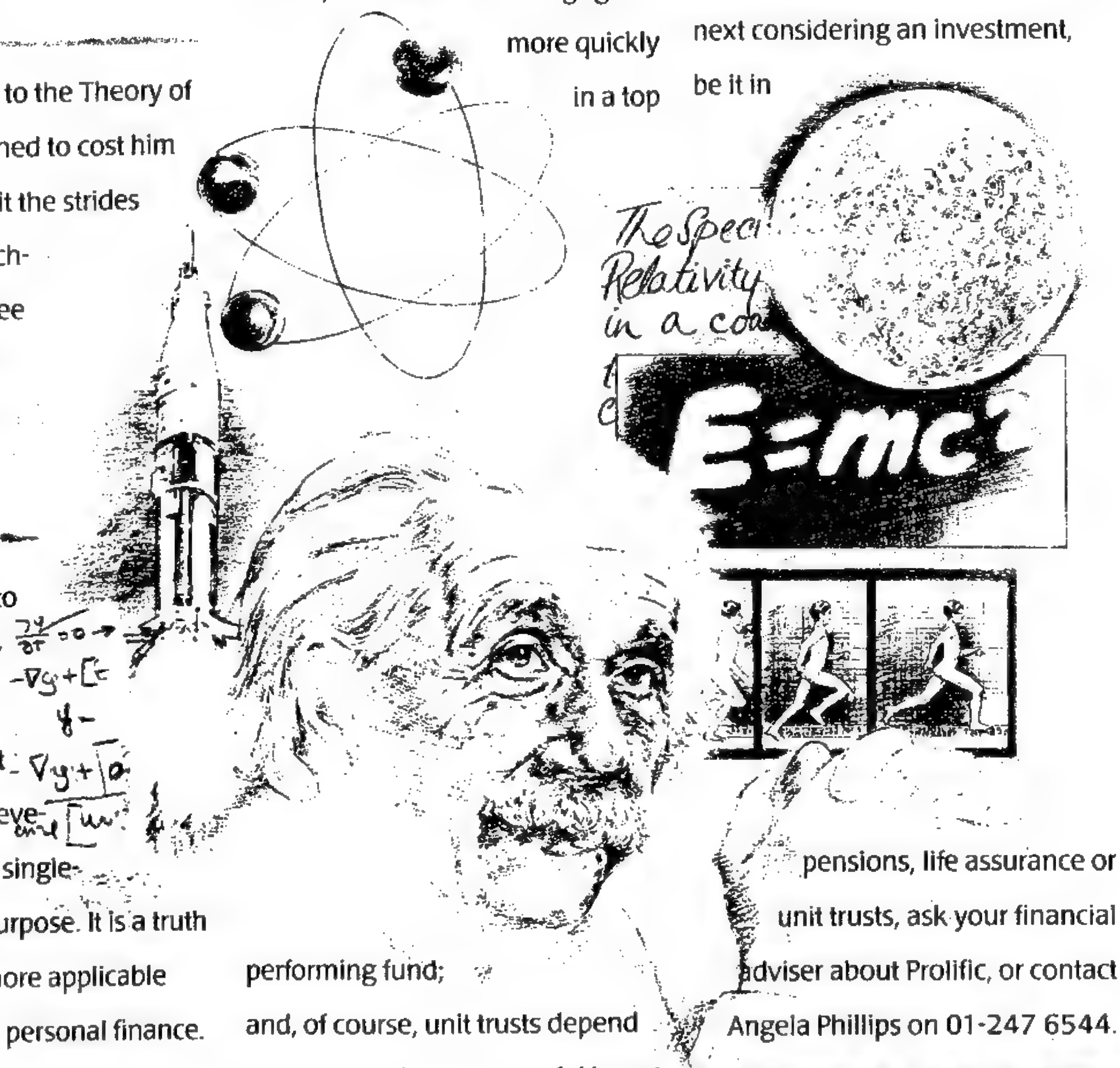
Albert Einstein flew in the face of convention, risking reputation and indeed health in his pursuit of the idea that was to culminate in the most famous equation of the 20th Century.

His dedication to the Theory of Relativity threatened to cost him dear. Yet without it the strides in science and technology we now see as commonplace could never have taken place.

Einstein's will to succeed perfectly illustrates an important truth; that outstanding achievement arises from single-mindedness of purpose. It is a truth that's nowhere more applicable than the world of personal finance.

Prolific is one of the UK's most successful and highly regarded financial services groups. This has been achieved by being single-minded about the most important aspect of financial planning and management-investment performance.

Simply, your pension will pay you more if the pension fund is better invested; life assurance savings grow more quickly in a top performing fund; and, of course, unit trusts depend almost entirely on successful investment management.



At Prolific, our aim is consistently good investment performance; in 1983, we won the Observer award for the 'Smaller Unit Trust Group of the Year' and the Sunday Telegraph voted us 'Unit Trust Group of the Year' for 1987.

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Prolific
FINANCIAL MANAGEMENT

Committed to your investment success

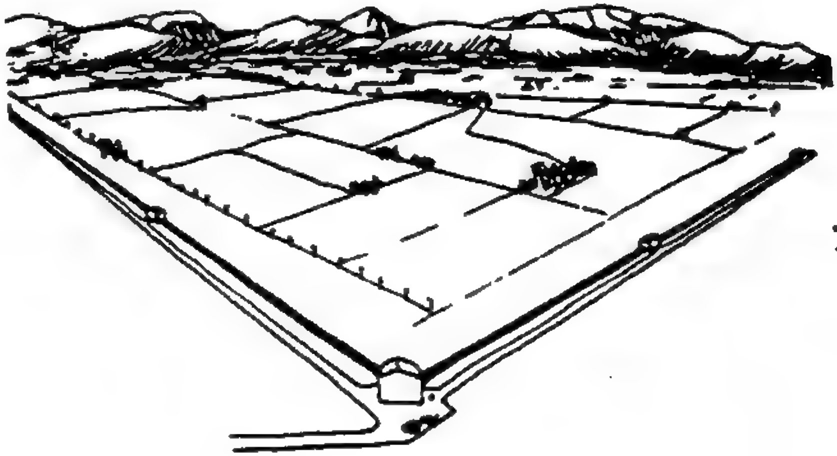
G/031/1088A

PLEASE REMEMBER THAT PAST PERFORMANCE IS NOT NECESSARILY A GUIDE TO THE FUTURE THE PRICE OF UNITS AND THE INCOME FROM THEM MAY GO DOWN AS WELL AS UP.

New Scientist 21 January 1989

New gravity telescope will probe collapsing stars

BRITAIN'S Science and Engineering Research Council (SERC) has drawn up a plan for four major telescopes that it will construct over the next decade. The most revolutionary is an instrument to detect—for the first time—gravitational waves from collapsing stars millions of light years away.



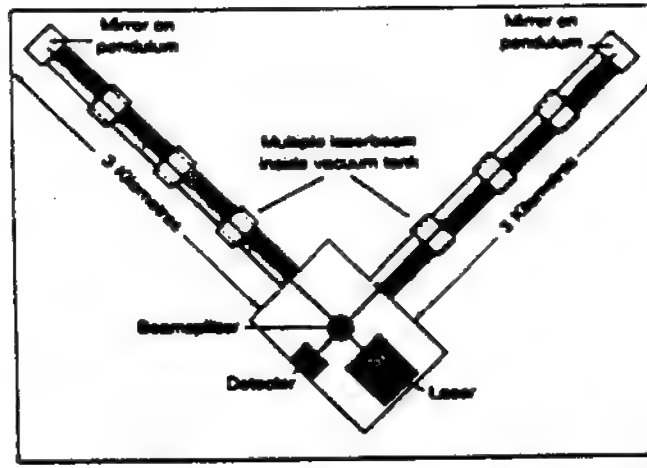
Hough's plan for an observatory to measure gravitational waves. It comprises two tubes excavated in the Scottish countryside, each up to a kilometre long

New Scientist 2 December 1989

Japan joins Australia on the crest of a gravity wav

The Japanese scientists want to collaborate with Australia on the building of a gravity-wave telescope because Japan suffers from a high level of seismic activity.

The Australian scientists are still waiting for a decision from the Australian Research Council on its request for more than A$30 million (around £15 million) for the project.



The new wave in gravity detection: essentially a larg optical interferometer

New ways with gravity waves

There is a chance that the United States will have a detector capable of recognizing gravity waves in the next few years. But the federal budget deficit may be a hindrance.

The California and Massachusetts institutes of technology (Caltech and MIT respectively) are traditionally proud of their differences, sometimes recognizable as rivalry, but they have for some months been breaking new ground by working together on a joint application to the US National Science Foundation (NSF) for what will be the next gravity-wave detector most likely to succeed.

SLIDE 3

Newton's law comes under attack

THREE HUNDRED years after the publication of Isaac Newton's *Principia*, his law of gravity is coming under more intense scrutiny than ever before. The suggestion that there might be more to gravity than the famous inverse square law hit the headlines in 1986, as a result of a new interpretation of exp... more t... Ephr... Washit... claime... that th... bodies... well as... lines a... four fo... gravit... and we... there... observ... revisi... *Revie*... Frank... sity of... assesse...

...appropriate at very large distances by a ... a small number ...

in the laboratory. If the two values of *G* were the same, that would prove that the α term is zero. ... complicated by the ...

Fifth force found?

A SCIENTIST at the Brookhaven National Laboratory, in New York, has come up with evidence that is "consistent with a substantial... medium ...

another because of the differences in the number of baryons in each nucleus. This ...

...ese claims involves ...re floating freely, ... water bath. The ... and is 21-11 ... balanced by six ... mass of ...

Force of a Different Color

New results bolster the case for a "fifth" fundamental force

Nearly two years ago Ephraim Fischbach of Purdue University and his colleagues caused a stir in the physics community with a report that experimental data collected at the turn of the century by the Hungarian physicist Roland von Eötvös contained evidence of another fundamental force in ...

others appeared ... by a group headed ... of the University ... performed what ... most sensitive test ... Coupled with the e... results appear tan... tent with the existe... diate-range, compo... force, albeit one wh... les not with the tota... trons and protons p... but with the differen...

Fundamental forces

In pursuit of the fifth force

E. Iacopini

NEWTON's theory of gravity assumes that the source of the gravitational force is ... inertial mass. As a ... and 10^{-n} ...

Icy tests provide firmer evidence for fifth force

Ian Anderson, San Francisco

an attractive force at different levels on a ...

theories of quantum gravity, the int... tion of three particles—the graviton, graviphoton and the graviscalar—c... produce two or more forces simil... gravity.

However, despite the results from G... land, the existence of the force has yet ... confirmed. "The biggest uncertainty i... experiment is still the density of the ... below the ice," said Goldman. Experim... to reduce this effect further are under... A team from Scripps has lowered a gr... meter to the bottom of a mid-ocean tr... between San Diego and Hawaii. T... results so far do not contradict those f... Greenland, scientists from Scripps ...

The 'fifth force' makes its presence felt

By Roger Highfield, Technology Editor

AN EXPERIMENT con...

weak nuclear force, which causes radioactive decay ... Los Alamos scientists think that their discovery may be the ...

Second helpings of the sixth force

Ian Anderson and John Gribbin

PHYSICISTS have found yet another force within Nature—which they have ... "fifth force" which effectively weakens ... range of a few metres. ... This new work ...

added five parts in 10 million to gravity's attraction. The effect remained after adjustments had been made for such influences as the tides, the changing water table, ... gravitational attraction of both ...

Physicists focus in on the fifth force

John Gribbin

TWO YEARS ago, a group of American scientists suggested that there might be another fundamental force in nature to add to the four existing forces—gravity, electromagnetism, and the strong and weak nuclear forces (*New Scientist*, 16 January 1986, p 16). Since then, physicists have carried out numerous experiments to test whether there truly was a "fifth force". The consensus that emerged from a meeting in London earlier this month to discuss the results of these experiments was that their original claims may have been mistaken, and that there is at present no firm evidence for a fifth force that depends on the composition of an object.

Ironically, however, research stimulated by these mistaken claims has produced strong evidence that there are deviations from Newton's law of gravity over ranges up to a few hundred metres. These deviations affect all objects equally, and may include both a repulsive fifth force and an attractive component; they can be explained within the framework of general ...

gravity, with the same constant of gravity applying to all objects. The re-analysis of their data suggested to Fischbach, however, that there was a very slight deviation from ...

G that Stacey finds, 1 per cent less than laboratory values.

How h... the force... holes, ... measure... provide... strata. A... estimate... differen... samples... Since th... proporti... decreas... 1 per c... calculat... Then... these r... to be lo... remote... rock an... to the... allowe... latious... overco... US A...

The stimulation of the fifth force

Nearly three years of ingenious searching may not yet have uncovered evidence that the fifth force ... kind of correction of newtonian gravity, is real, but the search itself has been rewarding.

Prospects for fifth force fade

Conflicting observations of the gravitational-like interactions which have engendered talk about a fifth force might have been reconciled

WHATEVER has happened to the fifth force? Eighteen months have passed since the existence of a non-newtonian interaction between massive objects was postulated by Fischbach, Sudarsky, Szafer, Talmadge and Aronson on the basis of their reanalysis of the measurements by Eötvös, in the 1920s, of the apparent 'gravitational' interaction between objects of various composition.

That the old data are shot through with anomalies is not surprising. What ...

Univ... woul... tiona... age ... gravi... differ... resen... times... Britai... faces... spring...

R.I.P. fifth and sixth forces

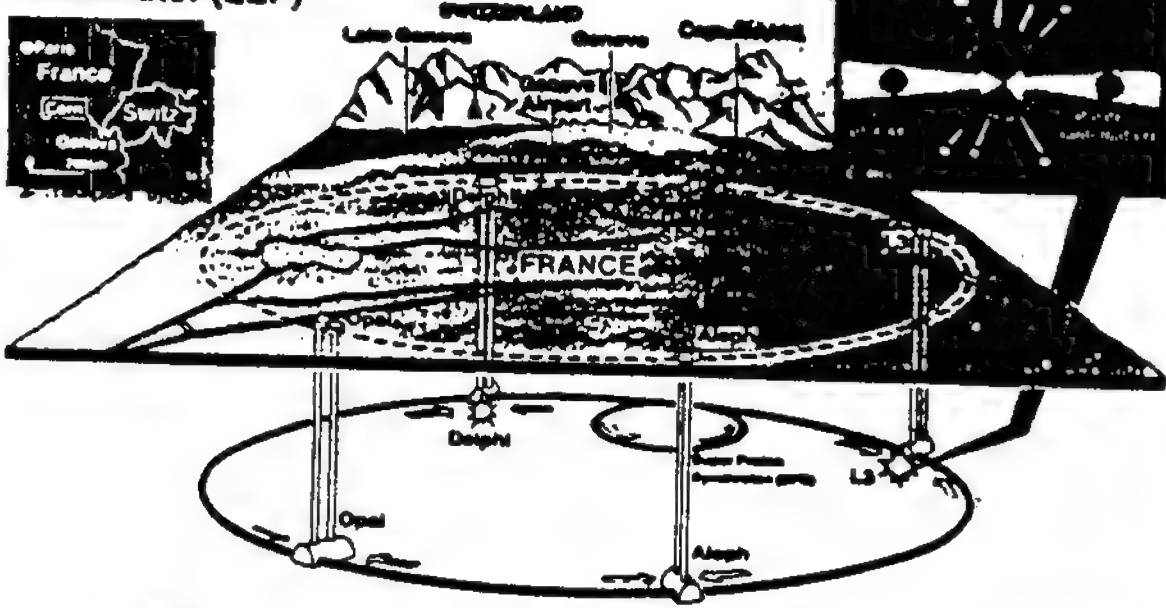
Evidence has previously been presented in these pages (June, 1988) for the existence of the so-called fifth and sixth forces in Nature. Hitherto every interaction had been ascribed to one of four well known forces: the electromagnetic force, the weak nuclear force, the strong nuclear force and gravity.

Belief in the existence of further ...

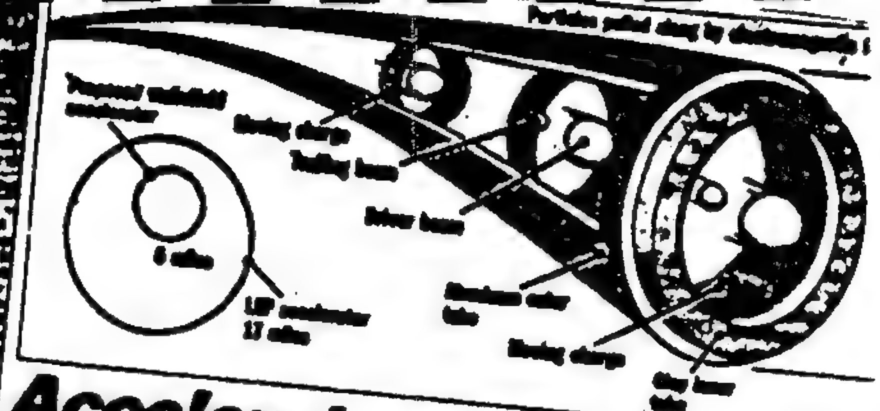
...itive result off the Palisades cliffs ... what it is worth, θ comes out at ... o are the two apparently conflicting measurements merely manifestations of the same underlying phenomenon? ... itive test of how good the fit may be ... lberger *et al.* now simply figure ...

SLIDE 4

Large Electron Positron Accelerator (LEP)



LEP and Big Physics



Accelerators speed costs

SCIENTISTS probing the mysteries of matter have reached a barrier almost as daunting as any created by nature: particle accelerators, such as the one opened this year near Geneva, which is as long as a whole line on the London Underground, have grown so big that they are becoming too expensive to build.

PHYSICS

● A way is being found to overcome the cost of particle colliders, reports

by an oscillator. This affects the empty space in the cavity the way shaking of one end affects a clothes-line; it creates a wave. A charged particle injected into a trough of such a radio wave is carried along at nearly the speed of light, picking up energy from

Early Z^0's encourage CERN physicists

OPAL

HIGH-ENERGY PHYSICS

Beaming in on the Z^0 particle

David J. Miller

WITH four particle accelerators now available with sufficient energy to produce the Z^0, one of the most interesting particles in fundamental physics, many exciting results can be expected. Preliminary ... from two of these ...

than previous values, obtained at the CERN SPS proton-antiproton ... The published ...

of the ... Instead of ... able in fitting ... curve, the ... alternative ...

Smashing electrons reveal all

CERN's massive new atom-smasher, the Large Electron Positron collider ... mid-June under

they break up. It's like trying to study the innards of a chip using a hammer.

What CERN scientists hope will

together electromagnetism, forces and gravity. (Britain ... ly, is heavily involved in A... and Opal; together with ot... CERN's work, they receiv... per annum from the Gover...

As well as W and Z par... researchers will also be ... Higgs particles, hypothet... ners which appear only

What is an electron?

A new model: the phase-locked cavity

£1bn machine to seek the source of gravitation

By Tom Wilkie

SCIENTISTS from across Europe next week start in earnest a search for the source of gravitation, using the biggest and most complicated machine mankind has constructed.

The £1bn machine, a particle accelerator called LEP, is housed in a 27km tunnel running under the Franco-Swiss border just outside Geneva

ered in 1983 at another particle accelerator in the CERN laboratory. "But ... known," Pr...

"The be... they are democratic: ...

SLIDE 5

Eric Laithwaite defies Newton

he claimed, violated gravity and produced lift without any external reaction

The Professor of Engineering at Imperi... Eric Laithwaite, highly... tor of the linear moto... sacrosanct domain o... engineers. And be say... Last Friday as the pie... his evening discourse... tution he demonstrat...

Scots genius heads for the stars

by MICHAEL SHANAHAN

DAY trips to Australia and weekend jaunts in the Milky Way could become a reality, thanks to the brainpower of a Scottish inventor.

Mr. Sandy Kidd's discovery, which is set to revolutionise travel, is sending shock waves through the scientific establishment already.

... Britain's top ...

setting gyroscopes at particular angles, a lifting force that defies gravity is produced.

Mr. Kidd, who worked for five years on his brainchild at ... home, is now ... of the

the travel industry. Taken to the ultimate, we will have planes without jet engines and helicopters without rotor blades."

Mr. Kidd is being financed by an Australian research company. A spokesman said: "We are on to something really big. The next stage is to power up Sandy's device in ... with the prospect

Does a spinning mass really lose weight?

Malcolm MacCallum

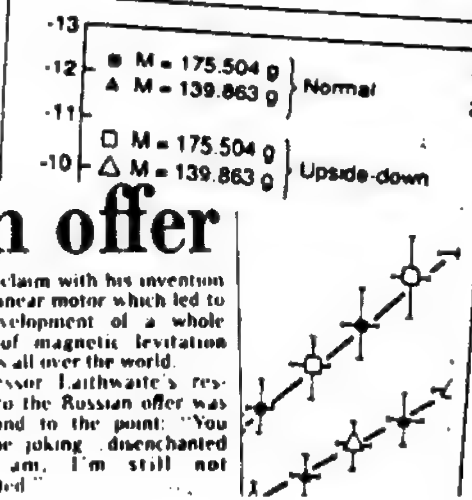
LATE last year, two Japanese researchers made the startling claim that when a gyroscope spins in one sense, it loses weight, but that its weight remains unaltered when it spins in the opposite sense. Other physicists are attempting to repeat the experiment, and, already, the first results are in.

The original experimenters, Hideo Hayasaka and Sakae Takeuchi of Tokohu University, placed a gyroscope on one arm of a chemical balance and spun the rotor by electrical means. They then measured the speed of its rotation.

Hayasaka and Takeuchi found that when a gyroscope spins in a clockwise sense—looking down on it from above—it loses weight. The amount it loses is only about five-thousandths of one per cent of its ... The researchers also ...

so-called "systematic effects". These can produce results similar to the phenomenon the researchers intend to measure. Secondly, they ask whether the conclusion drawn by the experimenters is justified by the quality of their data.

In the case of Hayasaka and Takeuchi's experiment, there are two quite obvious



Gravity challenged

By Roger Highfield, Science Editor

URSDAY, FEBRUARY 8, 1990

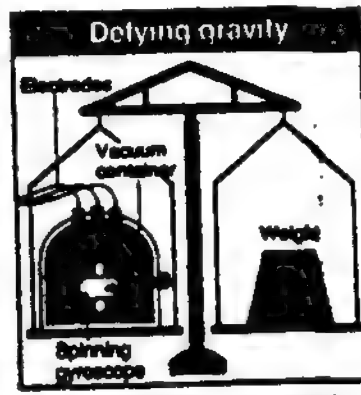
JAPANESE scientists claim to have defied gravity by using a spinning gyroscope.

Physical Review Letters, an organ of the American Physical Society, has published details of ...ch small ... to lose ...ck-

...r of ...fice, ...ideo ...hi of ...ndai, ...d to

...blica- ...work ...ly be ...npt to

...ntists



The gyroscopes appeared to lose weight, the more as speed increased. The weight reduction ranged up to 11-thousandths of a gram ... turner ... thors ... weight reduction", when ...

Catch in Soviet cash offer

by Robert Porter

THE RUSSIANS have offered to finance an important British scientific research project after big business in this country failed to provide the necessary backing.

But the offer has had to be turned down because there was, of course, a catch. In return for

The Russians were particularly interested in experimental work carried out by Professor Eric Laithwaite of Imperial College, London, on an inertial thrust machine—a gyroscopic device to prove that a spinning wheel can radiate mechanical energy across a distance and affect another spinning wheel

wide acclaim with his invention of the linear motor which led to the development of a whole range of magnetic levitation vehicles all over the world.

Professor Laithwaite's response to the Russian offer was terse and to the point: "You must be joking ... disenchanted as I am, I'm still not interested."

Newton rules OK, decide gravity experts

SLIDE 6

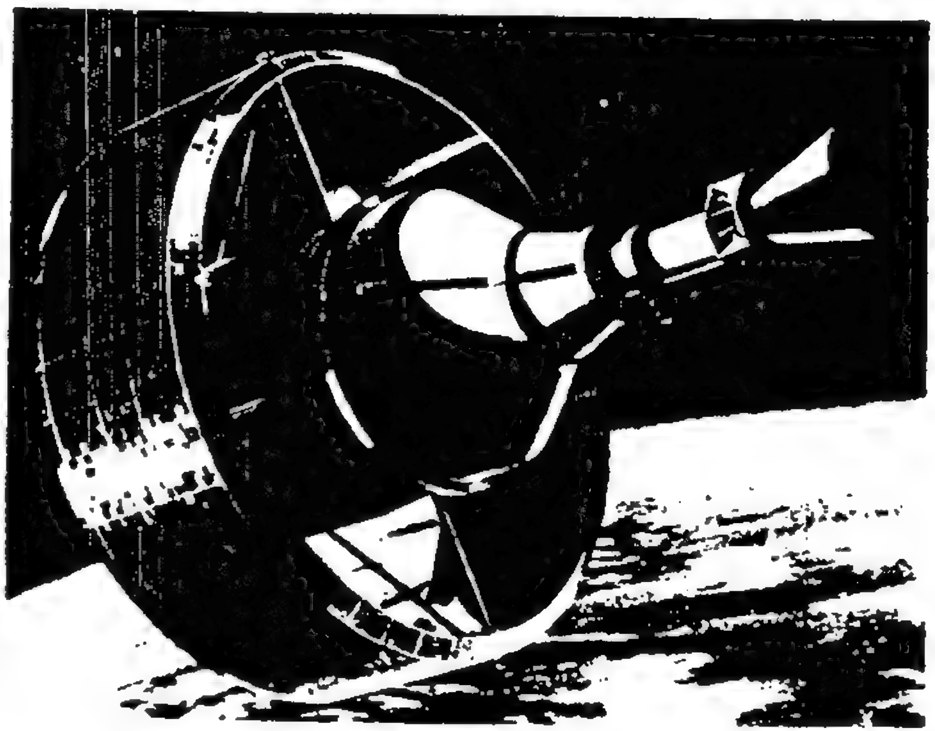
Testing Einstein (again) with a

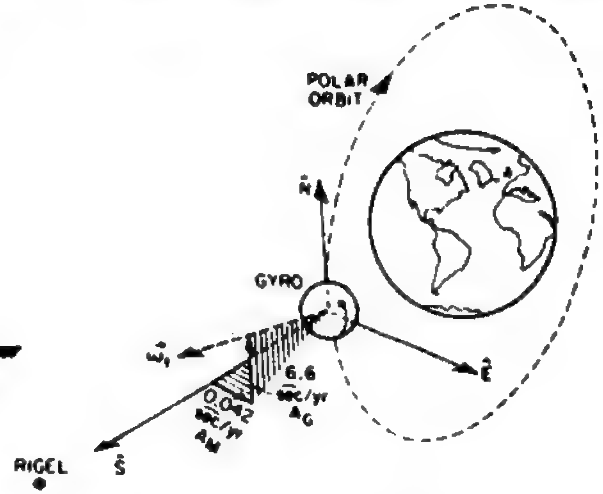
relativity satellite

What may be the most important physics experiment of the decade will carry the roundest objects ever made

By ARTHUR FISHER
PHOTOS BY MICHAEL FREEMAN

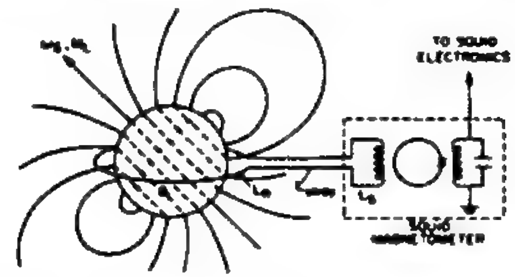
Earth, Columbus notwithstanding flattened at the poles and bulges at is both pitted and spiky. It has 29,000-foot Everest, and abysmal deep Mariana Trench.
Now imagine that Earth is with all the dimples and pim —so perfect that nowhere a!





- o 650 km polar orbit
- o line-of-sight to Rigel - in orbital plan
- o telescope/spacecraft pointed nominally a Rigel and rolling about line-of-sight to Rigel
- o rotor spin axis towards Rigel
- o 1 SQUID loop per gyro

STANFORD RELATIVITY GYROSCOPE EXPERIMENT
(NASA Gravity Probe B)



Superconducting gyroscope readout system.

SLIDE 7

FOUCAULT PENDULUM AT THE SOUTH POLE: PROPOSAL FOR AN EXPERIMENT TO DETECT THE EARTH'S GENERAL RELATIVISTIC GRAVITOMAGNETIC FIELD

An experiment is proposed for measuring the earth's gravitomagnetic field by monitoring its effect on the plane of swing of a Foucault pendulum at the south pole ("dragging of inertial frames by earth's rotation"). Current technology might permit a 10 per cent experiment in a measurement time of several months.

Gravity Gradiometry

SOMETHING NEW IN INERTIAL NAVIGATION

By MARK A. GERBER
The Charles Stark Draper Laboratory

By opening the way to highly accurate inertial navigation systems, gravity gradiometr promises to increase greatly the effectiveness of mobile ballistic missiles

An inertial navigation system uses gyroscopes to maintain a known reference frame in which a celerometers measure accelerations when nongra tational forces cause changes in the vehicle's hea ing and speed. Application of Newton's laws allo integration of the measured accelerations to obt the vehicle's velocity and position. Because it c operate without external references in hostile a remote environments, an inertial navigator pro attractive for military applications. It will not veal the vehicle's presence by radiating and it c not be jammed.

Since the first successful flights of ine navigation systems early in the 1950s, technology has been paced by improvement gyroscope and accelerometer quality. This rou "ultimate" inertial navigator has now fundamental limits tc accelerom

Floated Gravity Gradiometer

MILTON B. TRAGESER
Charles Stark Draper Laboratory

I. INTRODUCTION

The floated gravity gradiometer was conceived in 1966 with the recognition that gravity disturbances wou soon limit inertial navigation system performance. A cylindrical version was first working early in 1972, and by 1973 it was demonstrating a capability of measuring 0.5 Eotvos [6, 7], a remarkable achievement at the time. The design of the current spherically configured floated gravity gradiometer was started in 197 worked in September 1976. major advan gradient torq level of matu develop a pro perhaps most

Inertial Technology for the Future

There are many different approaches to inertial be useful a concept has to be sound, but success is solving myriads of design details. The concept of the suspended gyro has been proven to be sound, but the Rockwell and Honeywell designs are quite different. The concept is sound, but

ROTATING ACCELEROMETER GRAVITY GRADIOMETER

It has been a long-standing goal of the geophysical and agencies of the Defense Department to of the gravity disturbance

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RESEARCH REPORT No. 461

MOVING-BASE ROTATING GRAVITY GRADIOMETER DEVELOPMENT

Spherical Resonant Gyro

NASA
National Aeronautics and Space Administration

Superconducting Gravity Gradiometer Mission

SLIDE 8

Gravitational Wave Research

Introduction

A summary of the proposal for a Joint German - British Interferometric Gravitational Wave Detector (SLIDE 1) was presented by Mr. E. Morrison and Mr. A. Carmichael. The major collaborators in the UK are from the Universities of Glasgow and Cardiff and the Rutherford - Appleton Laboratory (SLIDE 2). Details of the prototype detector, to be built at Glasgow, were also presented.

Gravitational Waves

Gravitational waves were described as ripples in the space-time continuum resulting from a symmetric accelerations of mass (SLIDE 3). Very large masses and acceleration are required to produce gravitational waves of detectable magnitude because the gravitational interaction is quadrupolar in origin and propagates at the speed of light.

A table of possible sources of gravitational waves is shown in SLIDE 4, and SLIDE 5 illustrates the formation of a black hole or neutron star.

Gravitational Wave Detections

When a gravitational wace propagates through space it produces distortions in space-time which can be measured in terms of the time it takes for light to travel between two masses. For particles situated a few kilometers apart from the distortion of the intervening space caused by an incident gravitational wave is about 10^{-18}m (SLIDE 6). This is so small that it is necessary to use interference techniques, such as in a Michelson interferometer.

The optical path length used to measure the distortions (10^{-18}m) is very much less that the dimensions associated with the gravitational wave (300km). In these circumstances the quantity to be measured, the phase shift, is directly proportional to the length of the interferometric arms, so it pays to make the interferometer as large as possible.

The proposed detector uses laser inteferometry between freely suspended test masses shown schematically in SLIDE 7 and is based on a simple Michelson interferometer arrangement.

To increase the effective distance between the masses, the laser light can be reflected backwards and forwards several times in each arm.

The two separate techniques employed to increase the optical path length in the two arms of an interferometer are shown in SLIDE 8.

These are:-

(1) Optical delay line

(2) Fabry-Perot arrangement

In the Fabry- Perot system the optical beams are coincident, but in the delay line the laser beams are spatially separated.

The Fabry-Perot system offers several advantages but has many practical complications.

Advantages:-

* requires smaller mirrors.
* light beams occupy a much smaller volume in the interferometer arms.
* can have large number of effective traverses in the interferometer.

Problems:-

* need to have very high stability of mirror alignment.
* to operate the two arms must stay closely in resonance with the input laser light.
* control of the relative phase of the light returned from each arm.

Sensitivity and Noise Sources

The detection of gravitational radiation relies on sensing the strain in space induced by a wave of amplitude h, conventionally written as $2\frac{\Delta \ell}{\ell}$ where ℓ is the arm length, through its effect on the test masses.

The major source of noise in the system is associated with the statistical fluctuations of the photons forming the photoelectric current from the detector. Any induced phase shift within the interferometer must be detectable above the noise. If in time τ the average photon count is N, then analysis shows (SLIDE 9) that a sensitivity of approximately 10^{-22} is required to detect bursts of gravitational waves at 1khz.

There are several other noise sources (SLIDE 10) other than the photon counting fluctuations. The most important are:-

* quantum limit (Heisenberg Uncertainty)
* thermal noise
* seismic noise
* refractive index fluctuations in the vacuum
* optical noise

The significance of the noise sources is shown in SLIDES 11 & 12, taken from reference 1.

The 10m Prototype Detector at Glasgow University

The Fabry-Perot prototype detector at Glasgow has been under construction for the last 10 years. Most of the effort on the project has been associated with improving the sensitivity. Two periods of data collection have taken place.

The prototype detector (SLIDE 13) at Glasgow has two perpendicular arms each of 10m length. Four test masses are placed at the ends of each arm and ultra low loss dielectric mirrors are attached to the four test masses. Laser light, at 514nm, is obtained from an Argon laser and this reaches the cavities via a beamsplitter, polariser and quarter-wave plates. The beamsplitter and cavities are housed in a vacuum system at a pressure of approximately 5×10^{-4} mbar.

A Network of Detectors

Gravitational wave detectors cannot be operated alone. Detections must be confirmed by coincidence between two (or more) separated detectors. Even with two detectors it is not possible to deduce the full description of the gravitational wave (its amplitude, polarisation and direction of travel). Three detectors are the minimum required to deduce all the necessary information and four sites would be a sensible minimum given that some waves will travel in directions which are not optimal for detection. To provide this network a number of worldwide collaborative projects are planned (SLIDE 4).

Contributions to Scientific Knowledge

The whole project is expected to make significant contributions to scientific knowledge (SLIDE 15) in providing test of gravitational wave polarisation, speed of propagation of gravitational waves, tests of strong-field gravity. Astrophysicists will benefit from additional data on the early universe, cosmological mass distribution, Hubbles constant, compact-object statistics, equations of state for neutron stars, morphology of supernova cores.

I. Butchart

Ref. 1 Proposal for a joint German - British

Interferometric Gravitational Wave Detector

Max - Planck - Institut fur Quantenoptik

MPQ 147 (GWD/137/JH(89)) September 1989

GEO

A BRITISH / GERMAN COLLABORATION

Glasgow, Cardiff, RAL,
with MPQ Garching, LZ Hannover,
and PTB Braunschweig

SLIDE 1

GLASGOW

J. HOUGH
G.P. NEWTON
N.A. ROBERTSON
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B.J. MEERS
D.I. ROBERTSON
P.J. VEITCH

C.A. CANTLEY
A. CARMICHAEL
J.E. LOGAN
E. MORRISON
K.A. STRAIN

CARDIFF

B.F. SCHUTZ
& Colleagues

RAL

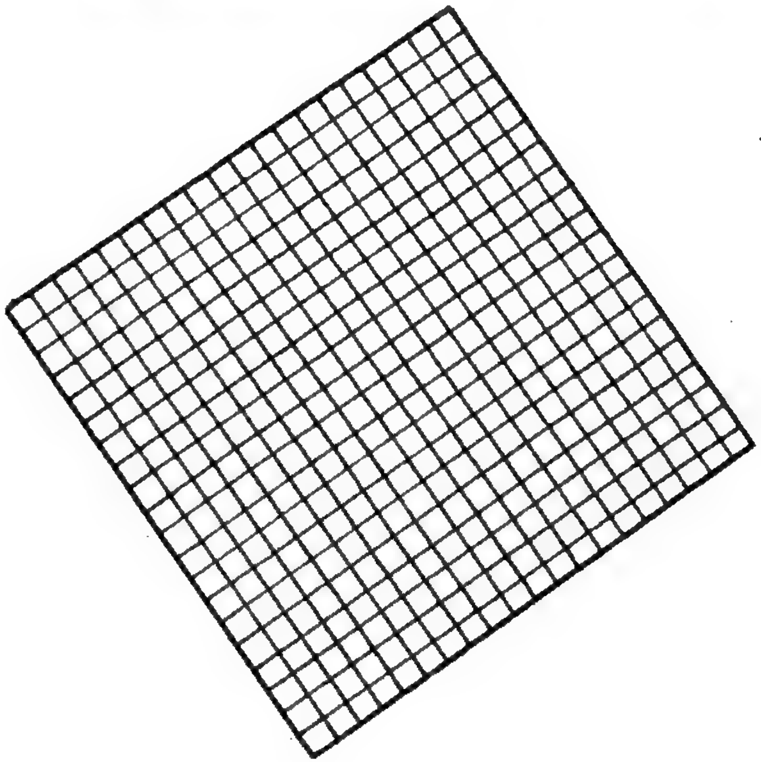
I.F. CORBETT
J.R.J. BENNETT
R.J.S. GREENHALGH

SLIDE 2

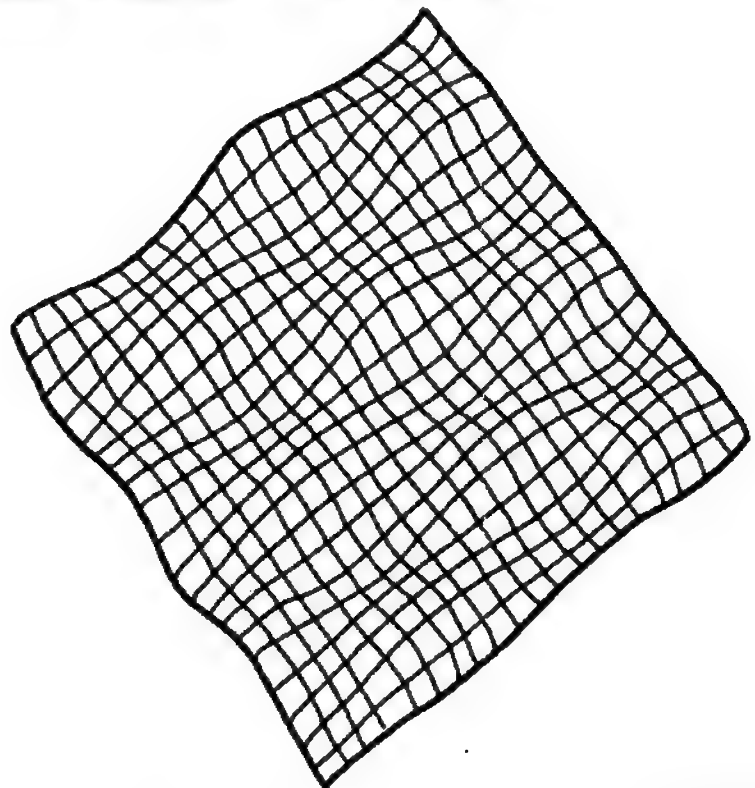
WHAT ARE GRAVITATIONAL WAVES ?

- ripples in space–time resulting from asymmetric accelerations of mass

- a prediction of GENERAL RELATIVITY



undistorted



distorted

SLIDE 3

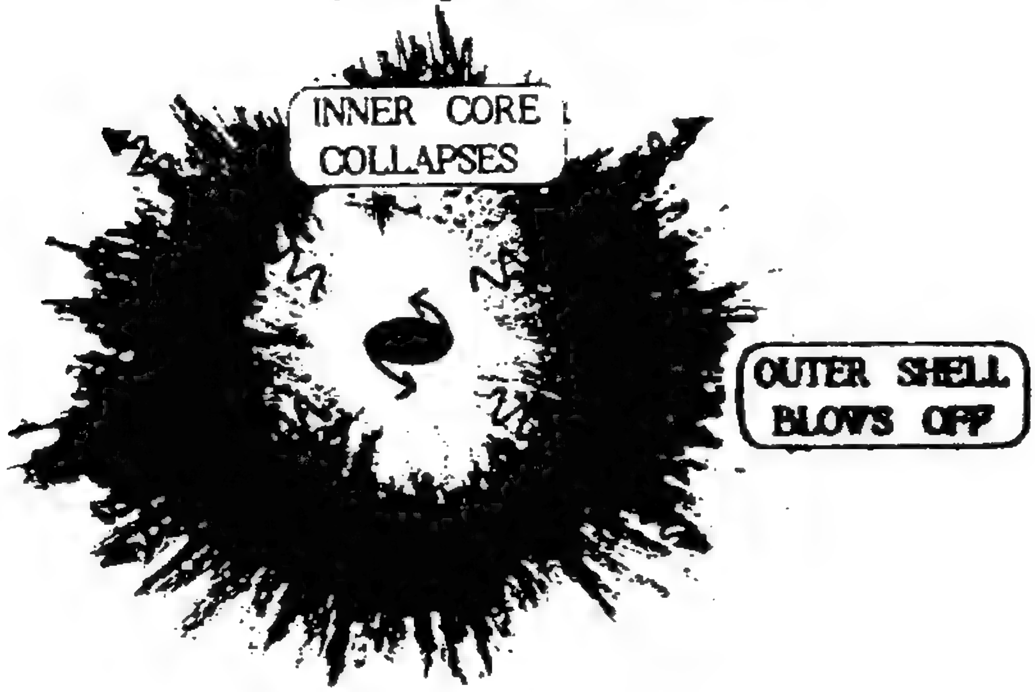
SUMMARY TABLE OF GRAVITATIONAL WAVE SOURCES

		IN A NETWORK OF 4 DETECTORS SENSITIVITY ~ 10^{-22}	
SOURCE	EXPECTED FREQUENCY	RANGE	EVENT RATE OR NUMBER
Supernovae	1 - 10 kHz	~ 50 Mpc	10^{2} / yr
Coalescing Binaries	10 - 300 Hz	NS - NS : ~ 1 Gpc BH - BH : ~ 9 Gpc	10^{3} / yr 10 / yr
Known Pulsars	< 100 Hz	few kpc	a few objects
Dead Pulsars	< 2 kHz	≤ 1 kpc	10^{4} ?
Wagoner Stars	0 - 5 kHz	few kpc	~ 10 possible
Stochastic background	any	——	——

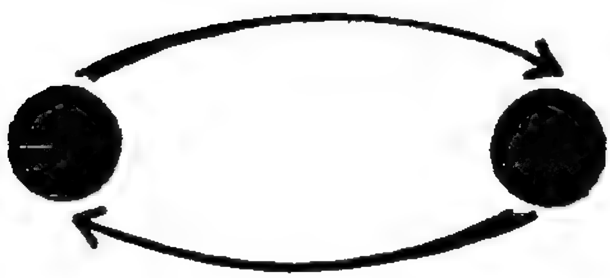
SLIDE 4

SOME POSSIBLE SOURCES

a) Stellar collapse to black holes or neutron stars (supernovae)

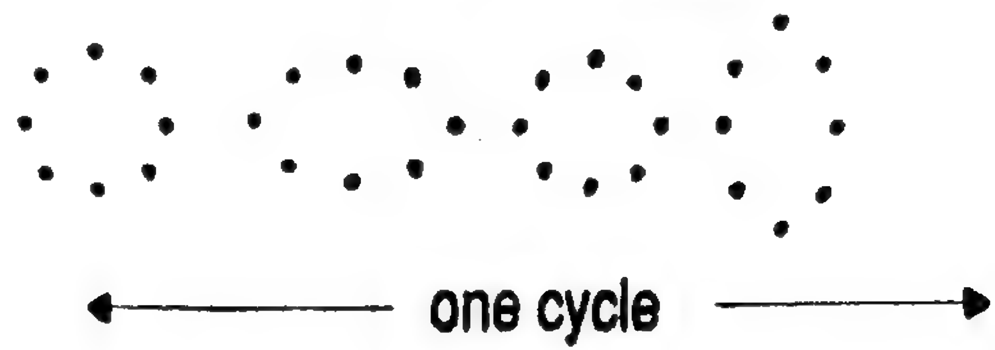


b) Coalescence of neutron star or black hole binary systems



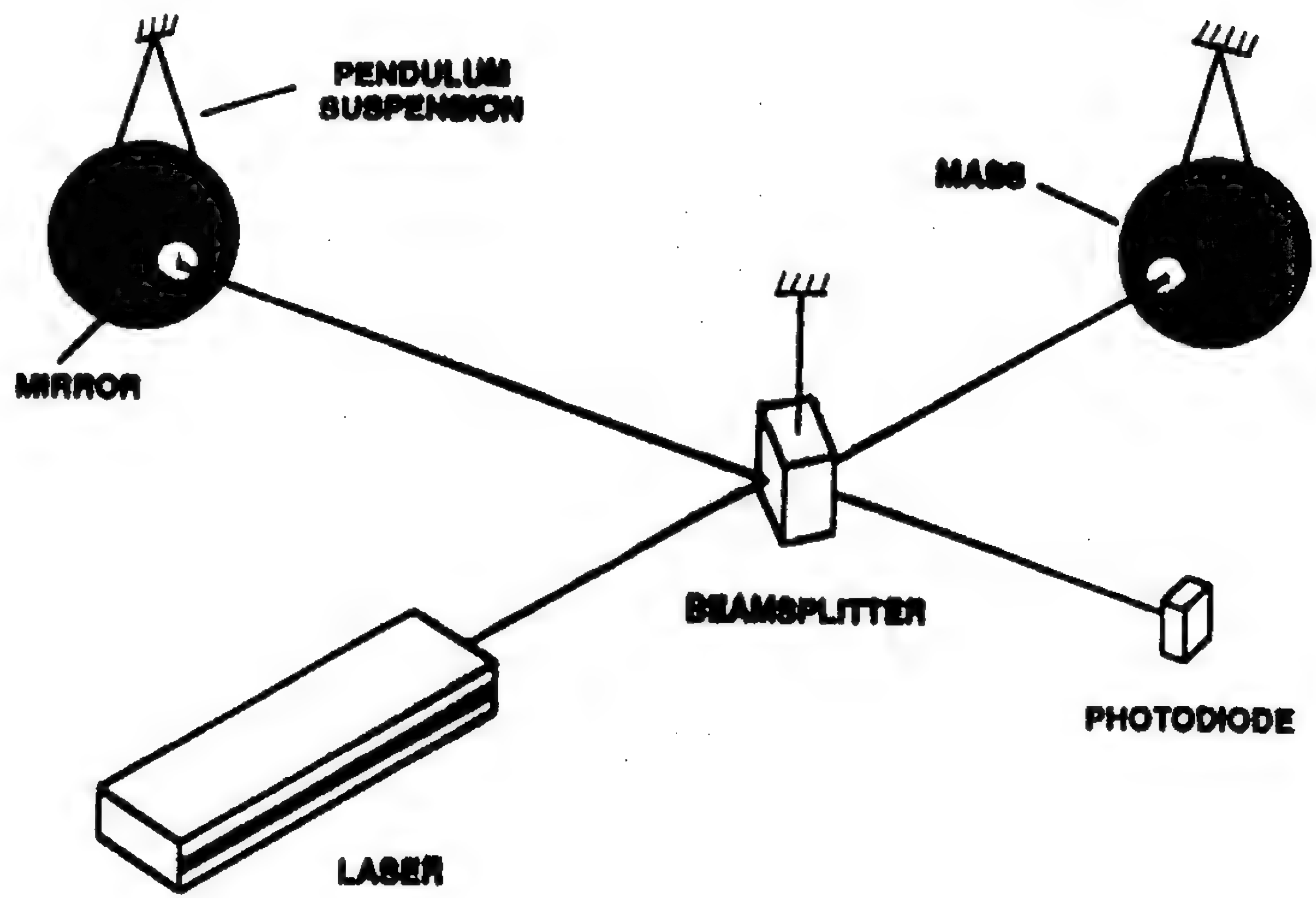
DETECTION OF GRAVITATIONAL WAVES

consider the effect of a wave on a ring of free particles



expected distortions are very small, corresponding to distance changes of less than 10^{-18} m between particles or masses a few kilometres apart

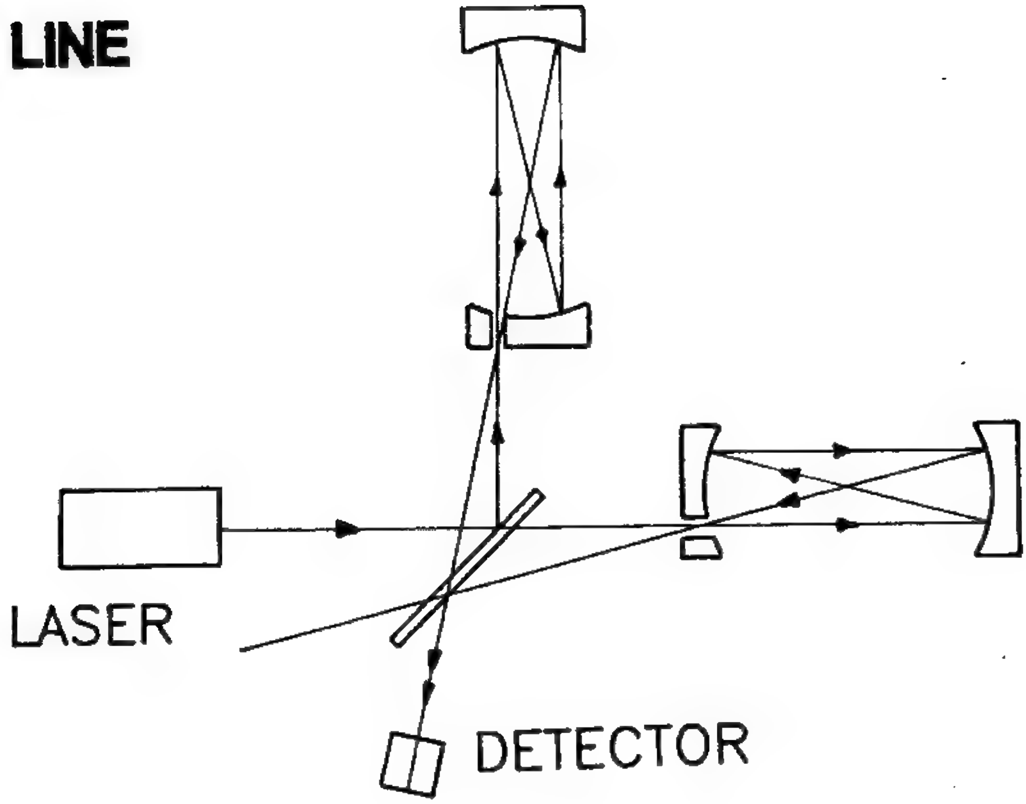
LASER INTERFEROMETRY BETWEEN FREELY SUSPENDED TEST MASSES



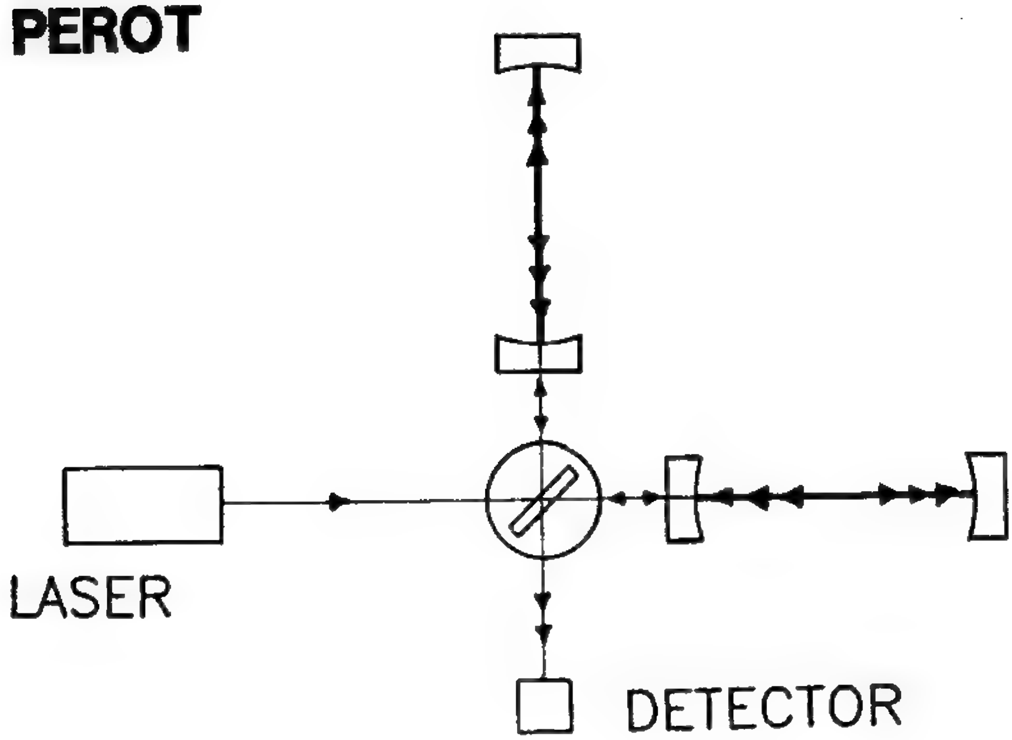
Layout of detector showing pendulums

SLIDE 7

DELAY LINE



FABRY PEROT

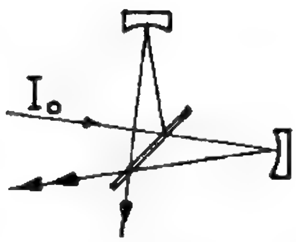


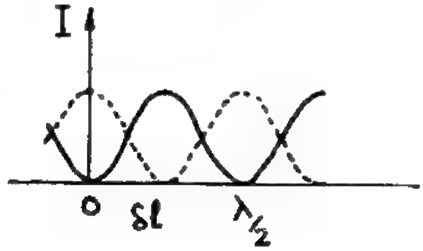
PHASE COMPARISON OF BEAMS FROM CAVITIES

SLIDE 8

DETECTION OF MOTION OF THE TEST MASSES

- Photon Noise limit to fringe detection





Since $\quad \Delta N \,.\, \Delta\phi \sim 1$

where N is number of photons in time τ and $\phi = \frac{4\pi}{\lambda} \,.\, \delta l$ is the phase difference between the light from the two arms of the interferometer

$$h \sim 2\frac{\Delta l}{l} \sim \frac{1}{l} \cdot \frac{\lambda}{2\pi} \cdot \frac{1}{\sqrt{N}}$$

$$\sim \frac{1}{l}\left(\frac{\lambda \hbar c}{2\pi I_o \tau}\right)^{1/2}$$

==> $I_0 \sim 3.5 \times 10^4$ W to reach $h \sim 10^{-22}$ for $\tau \sim 10^{-3}$ s

Formidable Requirement

Situation helped greatly by multipass arrangement

– multiplies up apparent movement

Multiple Beam Delay Lines

(Germany, Japan)

or

Fabry Perot Cavities

(Britain, USA)

SLIDE 9

Some Limits to Sensitivity

1) Heisenberg Uncertainty Principle

2) Thermal noise - from suspensions
from masses

3) Seismic Noise

$\longrightarrow$ $h \propto 1/(\text{ arm length })$

4) Effect of Residual Gas

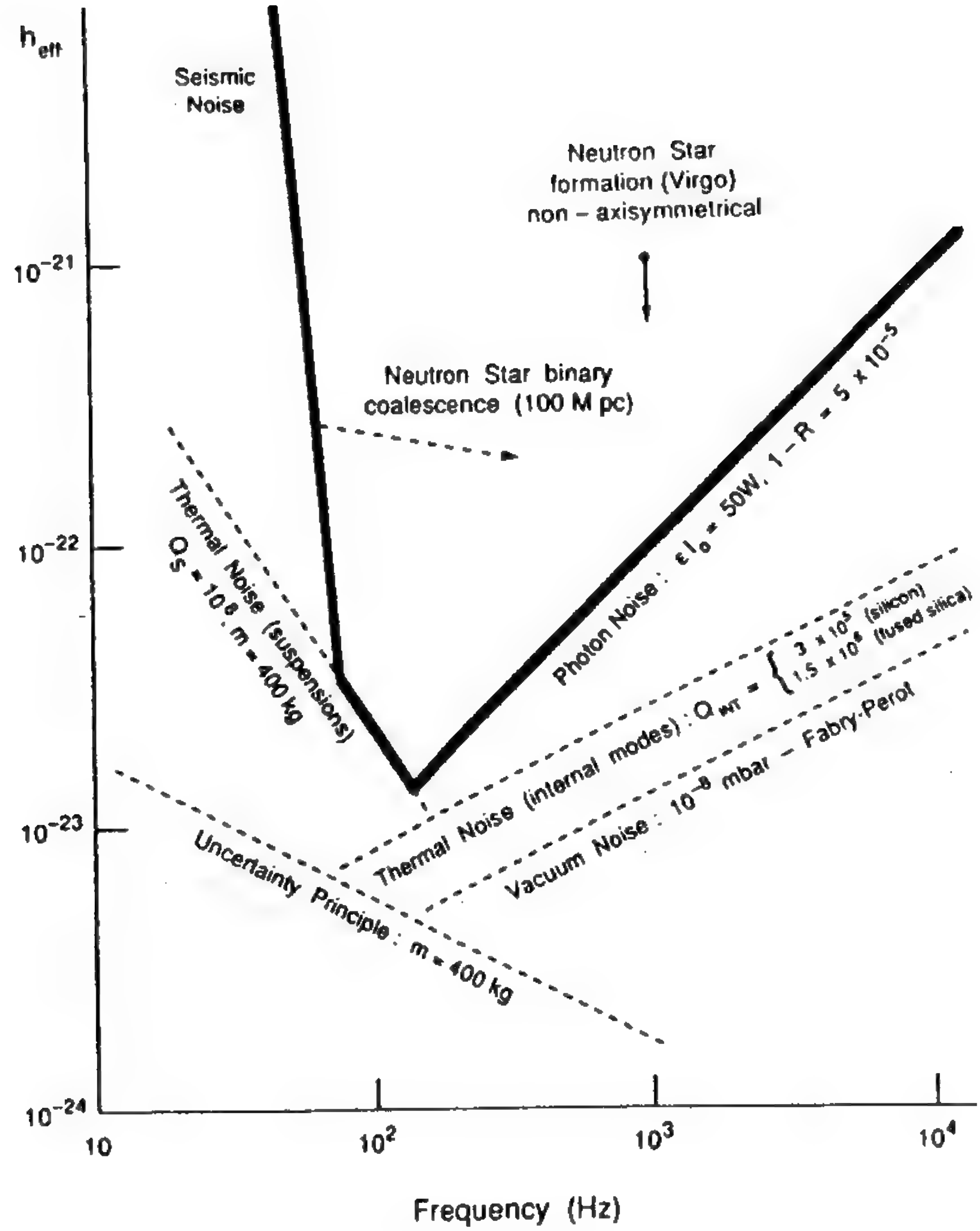
$$h \propto \frac{(\text{ pressure })^{1/2}}{(\text{ length })^{3/4}}$$

5) Photon Noise in Detected Light

$h \propto 1/(\text{ power x length })^{1/2}$

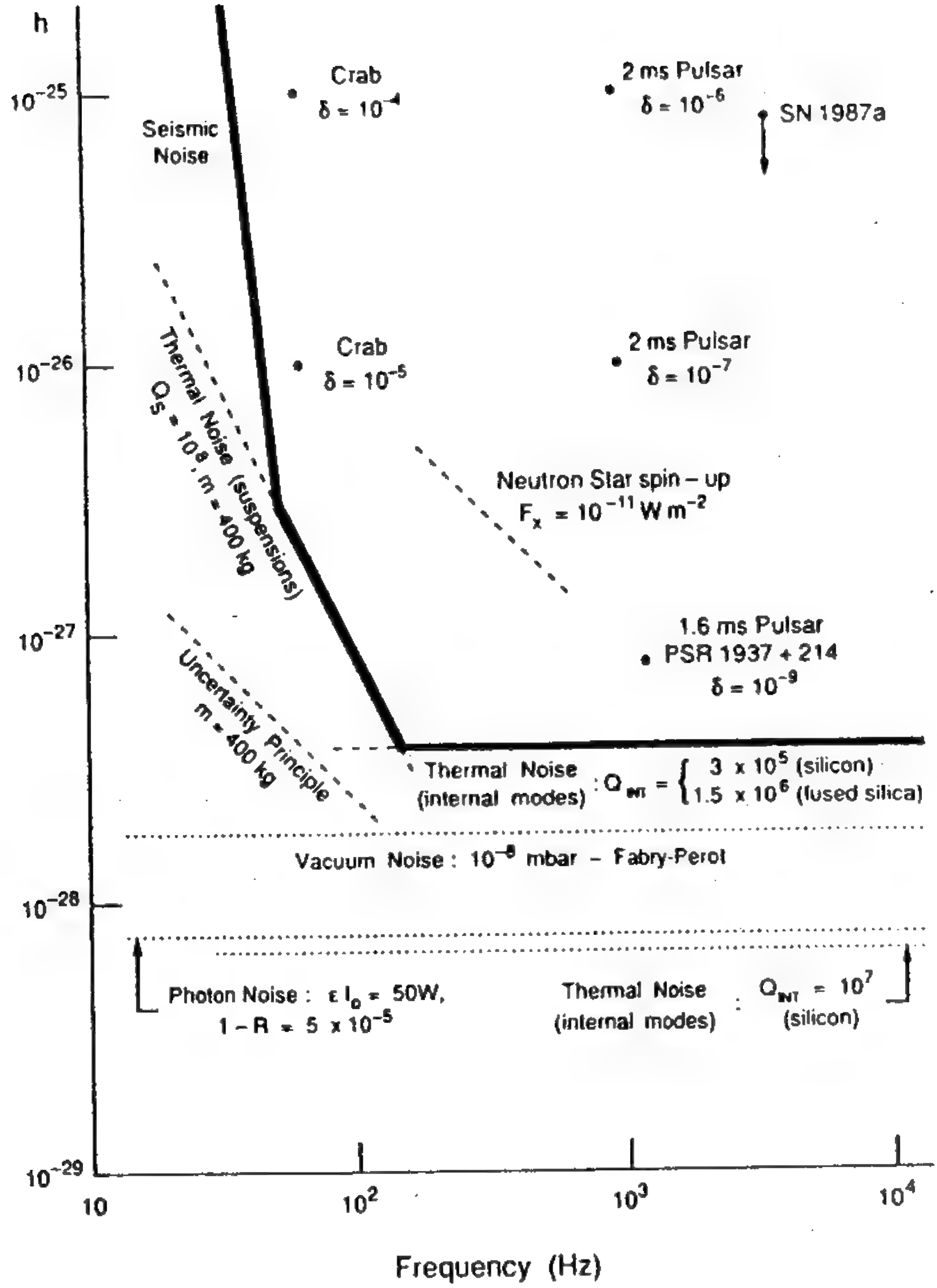
Achievable Parameters $\longrightarrow$ Length > 1km for desired sensitivity

$\longrightarrow$ L ~ 3km



Some burst sources and relevant noise levels. The ordinate is the effective amplitude h_{eff}, which is defined as $(S/N)\sigma_{bb}(f)$, where S/N is the signal-to-noise ratio given for different sources in the text and $\sigma_{bb}(f)$ is the value of the photon noise at the burst's central frequency f, as shown in the figure. For sources that have to be picked out by filtering, the effective amplitude is approximately $h\sqrt{n/2}$, where h is the true amplitude and n is the number of cycles of the waveform over which the signal can be integrated.

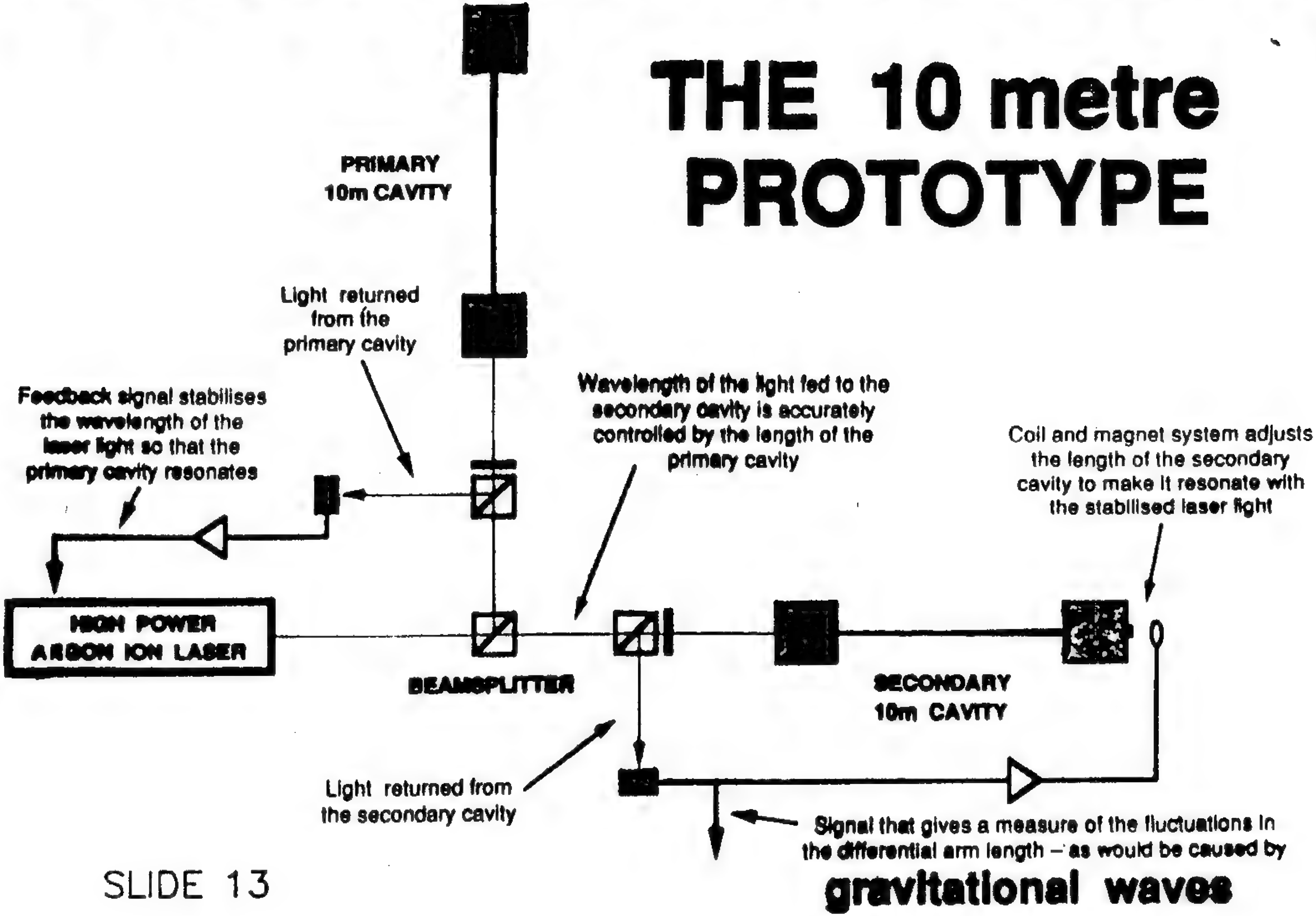
(Ref. 1 fig. 3.3)



Signals from possible sources of continuous radiation. An integration time of 10^7 s is assumed. Note that due to possible non-optimum relative orientation of source and detector, signal strengths may need to be reduced by a factor of up to $\sqrt{5}$. Thermal noise for Q_{INT} ranging from 3×10^5 to 10^7 is shown, representing estimated lower and upper limits to the internal Q of suspended masses.

(Ref. 1 fig. 3.4)

THE 10 metre PROTOTYPE



SLIDE 13

PROPOSED WORLDWIDE NETWORK OF DETECTORS

o Britain/Germany	3 km arm length
o Italy/France	3 km arm length
o USA (2 detectors)	4 km arm length
o Australia/Japan ?	3 km arm length

Detectors are also being considered by

USSR and India

Astrophysical Information from a Network of ~ 4 Detectors

1) Information on Compact Binary Coalescence Rate. Determination of Hubble's Constant (to a few % in a year) and surveys of the mass distribution of the universe.

2) Information on Stellar Collapse Rate and whether to Neutron Star or Black Hole. Location of a detected supernova in Virgo to within a few galaxies.

3) Information about the Early Universe from Measurements of Stochastic Background.

4) Information about Equation of State of Neutron Star Material from Observation of Pulsars or Rotating Neutron Stars.

5) Measurements relevant to Relativity Theory e.g.

   a) the relative velocity of gravitational and electromagnetic waves to ~ 1 part in 10^9 from supernova events.

   b) the determination of the polarisation states of the waves.

SLIDE 15

Fifth Force Experiments

The Physics Department at the University of Newcastle has a strong interest in gravitational physics. In particular, P.C.W. Davies, the Professor of Theoretical Physics, is a well known broadcaster on gravitational physics and has written a number of popular books about the subject.

The recent speculation about the possible existance of a 5th fundamental force of nature (SLIDE 1) has aroused much interest within the Physics Department (ref.1). A group, including Professor S.K. Runcorn, R.M. Hill, M. Gross et al, have been carrying out a series of preliminary experiments in order to investigate methods which might feasibly be employed to check claims of the existance of this 5th force.

Conventional gravitational theory is based on Newton's Inverse Square Law (SLIDE 2) which includes a constant of proportionality

$$G = 6.673 \times 10^{-11} \mathrm{m}^3/\mathrm{kg.\ s}^2,$$

known as the Universal Constant of Gravitation. A potential ϕ is derived such that the gravitational intensity is given by

$$\underline{g} = -\nabla\phi$$

At any point in a gravitational field a free test mass will experience an acceleration. According to the Principle of Equivalence the passive charge (m_g) of the test mass is exactly equivalent to the inertial mass (m_i) which develops. The force on the test mass can be considered in two ways (SLIDE 3). Either as that arising from gravitational attraction or as that due to acceleration. Galileo was the first to demonstrate that different masses fall together in a gravitational field indicating the equivalence of inertial and passive mass. Subsequent experiments by Newton, using a pendulum method, confirmed Galileo's observation.

Using a torsion balance, Von Eötvös showed that inertial mass is independent of a body's inner constituents (SLIDE 4). That is, a body's atomic structure apparently has no bearing on its inertial mass. The method employed by Von Eötvös was to allow the centrifugal force of the earth to act on different substances with the same passive mass (ie. $m_{g1} = m_{g2}$). This torsion balance experiment gave a null reading ($\Theta = 0$), showing that their inertial masses were the same (ie. $m_{i1} = m_{i2}$).

In 1986, E. Fischbach claimed that a re-examination of the original Von Eötvös results showed that in the near field there was a small departure from Newton's Inverse Square Law in apparent violation of the Principle of Equivalence. There were also, he claimed, indications that the deviation could be accounted for by a small force (a 5th fundamental force ?) dependent on the constituents of the body under test.

In connection with attempts to unify the forces of Nature, Fujii proposed that a Yukawa type term (SLIDE 5), operating out at a range (λ) of 100 metres, might be present in the force developed between two masses. This suggested the possibility of a slight variability in the value of G.

Under laboratory conditions ($r \ll \lambda$)

$$\underline{g}_{mod} = -\frac{GM}{r^2}(1+\alpha)\,\hat{r}$$

where the dimensionless parameter α has a strength of approximately 10^{-2}.

The possible existance of a 5th force received a further impetus when Stacey's calculation of G, based on gravitational intensity measurements (g) carried out in Australian mines was found to be 1% different from the free air value.

The underlying theory is based on Airy's method (SLIDE 6) of calculating G and relies heavily on a good knowledge of the earth's density distribution around the mine shaft. Other factors, including those effects due to earth's rotation, must also be accounted for (see ref. 2).

However, uncertainty about the density (ρ) measurements of the Australian work led to further g - measurements being made in bore-holes in Greenland's ice cap where, it was thought, the density distribution of the ice-sheet would be more uniform. Preliminary analysis of these results in 1988 seemed to confirm the existance of the 5th force, but doubts still persisted about the accuracy of the density distribution.

Before describing the experimental approach adopted by the Newcastle University group, Mike Gross gave a brief description of the apparatus used to measure changes in gravitational intensity. LaCoste & Romberg D-type gravimeters were used by the research group. SLIDE 7 shows a simplified diagram of the internal working of this type of gravity meter (see ref. 3). These devices measure relative changes in gravitational intensity and do not give an absolute value for g. The unit of change in gravitational intensity is the microgal, where

$$1\,\mu\text{gal} = 10^{-6}\,\text{cm. s}^{-2}$$

To overcome problems associated with poor knowledge of the density distribution of test masses, the Newcastle group suggested the novel idea of using large controlled volumes of water (with uniform density) as their gravitational test masses. They proposed the following sources for consideration :-

1. Docks
2. Reservoirs
3. Sea Tides

The first gravimetric test measurements were carried out by the side of Ship-Docks. Initially at Dock 10, near Southampton, and then at the Harland & Wolf Dock, near Belfast.

The surface of the earth is subject to noticeable, cyclical changes in gravitational intensity due to all the heavenly bodies, but primarily the Moon and Sun. These temporal effects (SLIDE 8) must be allowed for at the test sites. They can be avoided by using two gravimeters, at the top and bottom of the dock, and recording the difference in gravitational intensity. This is akin to measuring the local gravitational gradient in the vertical direction and is done both with, and without, the water in the dock.

Assuming that the body of water can be modelled as a rectangular block, the vertical component of gravitational intensity can be deduced analytically (SLIDE 9).

Measurements of the dock dimensions at Southampton were

Length = 365m, Width = 43m, Height = 17m

A calculation predicted that the change in vertical gradient intensity due to the body of water was about 120 μgals, whereas experimental measurements gave 86 μgals, which is of the right order.

The main causes of error were listed by the Newcastle group as follows :-

1. Ground Loading

   Compression of the earth's crust beneath the body of water changes the apparent gravitational attraction of the earth. This is not due to a change in G but due to a very slight change in distance between the centre of gravity of the water and the centre of the earth. Changes in air-pressure can also give rise to a minor effect.

2. Inaccurate Contouring

   Geometrical errors in defining the boundary containing the water will clearly give rise to errors when calculating the gravitational attraction of the body of water. Thus, comparing predicted Newtonian results with real measurements in order to isolate 5th force effects is prone to error. Only a very close geometric model of the volume of water will suffice. The rectangular mass model employed for the dock full of water is not suitable, other than as a guide for the level of gravitational intensity expected.

3. Mass Loss

   Water seepage outside the control volume leads to a difference between the predicted Newtonian gravitational intensity and the measured gravitational intensity which could be misinterpreted as a change in G due to a 5th force effect.

4. Nearby Sources

The movement of nearby sources of mass, such as Sea Tides, must also be monitored and allowed for in measurements of gravitational intensity. They might also be a source of ground loading.

Only after all the above effects have been catered for can one begin to search for non-Newtonian effects highlighted by differences between predicted and measured gravitational intensities.

Trials at the Docks were not successful, since the volume of water was too small and not accurately modelled. (eg. channels, buttresses, sloping walls etc. were all ignored.) It was also realised later, that the gravimetric measurements were probably made too closely to the water surface and not at the optimum range. Sites 50 metres above and below the water level would have been better, and in line with the notion that the maximum 5th force effect occurs at about 100 metres range.

The Newcastle group next turned their attention to large reservoirs, whose volumes fluctuated fairly rapidly. The energy storage plant at Dinorwic, in North Wales, was their first choice. In any 24 hours the reservoir undergoes a number of cyclic changes in volume corresponding with the peaks and troughs of the demand for electricity. The continual change of water level keeps the water well mixed and therefore of approximately uniform density.

The results obtained with the Dock experiments made it clear that a very accurate method of modelling the geometry of the body of water would have to be developed, with low error bounds, in order to isolate any non-Newtonian, perhaps 5th force, effects.

From Newtonian theory, the total potential of a distributed body, at an external point P, is given by (SLIDE 10) :-

$$\phi_P = -G \iiint_V \frac{\rho(\underline{r}')}{|\underline{r} - \underline{r}'|} \, dV'$$

so that the total gravitational field, for a body of uniform density ρ , is :-

$$\underline{g}_P = \rho G \iiint_V \nabla\left(\frac{1}{|\underline{r} - \underline{r}'|}\right) dV'$$

Applying the corollary from Gauss' Divergence therem we find :-

$$\underline{g}_P = \rho G \iint_S \frac{1}{|\underline{r} - \underline{r}'|} \, \underline{dS}$$

As a simple example we consider a spherical mass of radius a. To simplify the integration we let the origin coincide with the centre of the sphere and suppose that the external field point P lies on the z - axis. Furthermore, symmetry considerations show that on summing the elements, via integration, only the intensity in the z - direction is non-zero.

Therefore, in terms of spherical polars (r,θ,ϕ) :-

$$\underline{g}_P = \rho G \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} \frac{1}{s} \, (a\, d\theta)(a \sin\theta \, d\phi) \cos\theta \quad \hat{z}$$

where, on the surface of the sphere, $s = |\underline{r} - \underline{a}|$.

As shown in SLIDE 11, this gives :-

$$\underline{g}_P = -\frac{GM}{D^2}\hat{z} \quad \text{as expected.}$$

For more complex geometry we would have to resort to a numerical method for solving the integral.

Max Hill gave an alternative derivation, as follows. Suppose $\Gamma(\underline{r} - \underline{r}')$ is a Green's function which expresses the potential at a field point $P(\underline{r})$ due to a unit mass source at $Q(\underline{r}')$. The total potential, at P, due to a body of volume V, with density varying as $\rho(\underline{r}')$ is :-

$$\phi_P = \iiint_V \Gamma(\underline{r} - \underline{r}') \, \rho(\underline{r}') \, dV'$$

The total gravitational field is given by :-

$$\underline{g}_P = -\nabla\phi_P = -\nabla \iiint_\infty \Gamma(\underline{r} - \underline{r}')\rho(\underline{r}') \, d^3 r$$

where $dV' \equiv d^3 r'$ and because $\rho(\underline{r}') = 0$ outside V.

Since the above integral is in convolution form we can rewrite it as :-

$$\underline{g}_P = -\nabla \iiint_\infty \rho(\underline{r} - \underline{r}')\Gamma(\underline{r}') \, d^3 r'$$

Therefore, since ∇ is a function of r :-

$$\underline{g}_P = -\iiint_\infty \nabla\left[\rho(\underline{r} - \underline{r}')\right] \, \Gamma(\underline{r}') \, d^3 r'$$

The only contribution to the integral is where the source density changes. For bodies of uniform density, $\nabla\rho(\underline{r} - \underline{r}') = 0$, so that the integral is zero everywhere except on the surface of the body. At the surface, $\nabla\rho(\underline{r} - \underline{r}')$ reduces to a Dirac δ- function normal to the surface so that the volume integral reduces to the surface integral

$$\rho \iint_S \Gamma(\underline{r} - \underline{r}')\ \underline{dS}$$

where, if $\Gamma(\underline{r} - \underline{r}')$ is the Newtonian Green's function, then

$$\Gamma(\underline{r} - \underline{r}') = G.\frac{1}{|\underline{r} - \underline{r}'|}$$

For complicated surfaces, where the integrand is not integrable analytically, resort has to be made to computational methods. The technique is to replace the surface of interest as closely as possible with a polyhedral surface. The plane facets of this polyhedron, which are polygons, may then be split up into triangles. Now the Newtonian Green's function can be integrated analytically over any plane triangular surface to give a scalar value (ref. 4). Associated with each triangle will be a unit vector normal to the plane surface and pointing into free space. The product of that unit vector and the scalar value gives the component contribution from the triangle. The total gravitational field of the body under examination is then evaluated from the vector sum of the components from all the faces.

This gravitational 'panel method' has great similarities with panel methods developed in other branches of potential theory. At BAe(MAL), panel methods are in standard use for modelling incompressible flow about aircraft structures and for modelling radar reflectivity from aircraft structures.

R.M. Hill et al (ref. 4) have developed a computer program to predict the gravitational field of any solid body. Details of the boundary surface (contours of the Dinorwic reservoir were provided by the CEGB) are fed into the computer as a series of nodes and the program semi-automatically panels the body and calculates the gravitational intensity at a given external field point.

The results of the work (SLIDE 12) carried out at Dinorwic showed that the gravimetric measurements were about 7% higher than the predicted values. However, a careful inspection of the reservoir sides revealed that much water was contained in broken rock, which could not be accurately included in the numerical model. Based on these results, no conclusion could be made about the existance, or non-existance, of a fifth force.

Gravimetric measurements are now being made at the upper reservoir at Ffestiniog, which has a less porous boundary, and we await the results of the analysis.

Mike Gross also described some preliminary ideas for using tankers at sea as large sources of moveable mass. Some gravitational measurements, carried out close to tankers in the Rotterdam-Europort, were illustrated during the Round Table meeting but, apparently, this approach was not pursued very far due to measurement difficulties.

A more simple method is to use the raising and lowering of water levels due to Sea Tides. The gravitational intensity due to an infinite sheet of matter of uniform density is $2\pi\rho G\ell$, where ℓ is the sheet thickness (ref. 3). Note that, surprisingly, this result is independent of the height (h) of the field point above the sheet. Mike Gross said that some test gravimetric measurements had been recorded at lighthouses (eg. The Bishop Rock lighthouse). In analysing these measurements it was necessary to account for the plug of different density (ie. the lighthouse base) within the infinite sheet.

In a similar way, in the US, gravimetric measurements have been recorded at various heights up a TV mast. In this case a detailed geological survey of the surrounding land was available.

By replacing the Newtonian potential with the Yukawa form the effect of a 5th force can be calculated theoretically. By varying the parameters to obtain a fit of the predicted results with those measured experimentally it is possible to gain estimates of the dimensionless parameter α and the scale range factor λ.

At the moment, over the range measured, the University of Newcastle group feel that their results indicate the non-existance of the 5th force. However, a definitive statement will have to await the completion of their researches, probably at the end of the year.

After the presentation, Professor Donaldson commented that the use of a gradiometer might provide a simpler method for checking the validity of Newton's Inverse Square Law. Indeed, Paik (ref. 5) has suggested that as part of the Superconducting Gravity Gradiometer Mission, the space-borne gradiometer may be used to determine the value of $\nabla^2\phi$. A null test result, showing that Laplace's Equation is zero, would confirm the validity of Newton's Inverse Square Law. However, a non-zero result would give a direct measure of α and λ.

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The 4 – Fundamental Forces of Nature

1.	Gravitation	Macroscopic Forces
2.	Electromagnetism	
3.	Strong Nuclear attraction	Microscopic Forces
4.	Weak Nuclear attraction	
5.	?	

SLIDE 1

Newtonian Gravitational Theory for point sources

From the Inverse Square Law, the gravitational intensity $\underline{\mathfrak{g}}$ at a distance r from a point mass M is given by

$$\underline{\mathfrak{g}} = -\left(\frac{G\,M}{r^2}\right)\hat{r} = -\frac{\partial}{\partial r}\left(\frac{G\,M}{r}\right)\hat{r}$$

$$= \underline{g} \quad \text{if} \quad M = M_E = \text{mass of earth}$$
$$\& \quad r = R_E = \text{earth's radius}$$

where $G = 6.673 \times 10^{-11} m^3 kg^{-1} s^{-2}$ = Universal constant of Gravitation

The Newtonian potential ϕ is

$$\phi = -\frac{G\,M}{r} \qquad \text{so that} \qquad \underline{\mathfrak{g}} = -\nabla\phi$$

The Principle of Equivalence

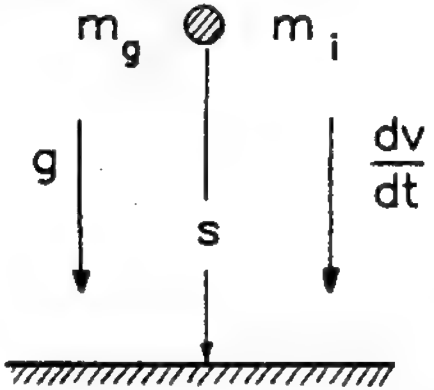
A free test mass (m) placed at any point in a gravitational field will experience an acceleration such that

passive gravitational charge $(m_g) \equiv$ active inertial mass (m_i)

Consider a body falling in a gravitational field

Inverse Square Law

$$F = \left(-\frac{G\,M}{r^2}\right) m_g = g\, m_g$$



Newton's 2nd Law

$$F = m_i \frac{d}{dt}(v) = m_i \frac{d^2}{dt^2}(s)$$

Equating forces and integrating gives $\quad s = \frac{1}{2}\left(\frac{m_g}{m_i}\right) g t^2$

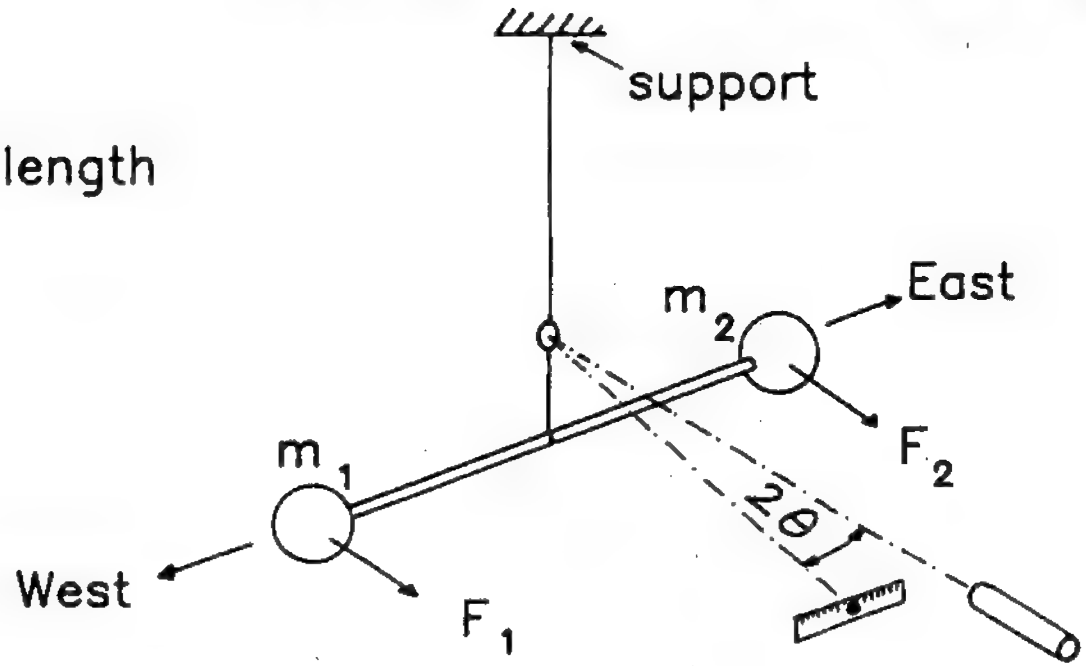
where distance $s = 0$ & velocity $v = 0$ when time $t = 0$

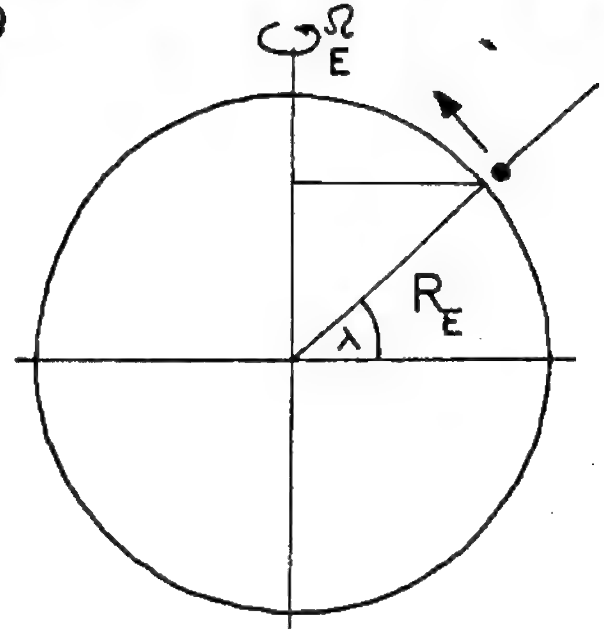
Galileo demonstrated that bodies of the same material, but with different masses fell together suggesting $m_i = m_g$

SLIDE 3

Von Eötvös Torsion Balance

a = bar length





horizontal force on mass $m = m\, R_E \Omega_E^2 \cos\lambda \sin\lambda$

Couple $C = \underline{a} \times (\underline{F}_1 - \underline{F}_2) = a\, (m_{i_1} - m_{i_2})\, R_E \Omega_E^2 \cos\lambda \sin\lambda$

Also, $C = -\, k\theta$ where k = torsional stiffness of wire

Initially set-up balance arm in East – West direction.

After settling, rotate support by 180°.

$$2\theta = \frac{1}{k}\, a\, (m_{i_1} - m_{i_2})\, R_E \Omega_E^2 \cos\lambda \sin\lambda$$

SLIDE 4

The Yukawa Term

The modified Newtonian potential is

$$\phi_{mod} = -\frac{G\,M}{r}\left(1 + \alpha\, e^{-r/\lambda}\right)$$

where scale factor $\lambda \approx 100$ m.

For large r, $\phi \rightarrow -\dfrac{G\,M}{r}$

The modified gravitational intensity is

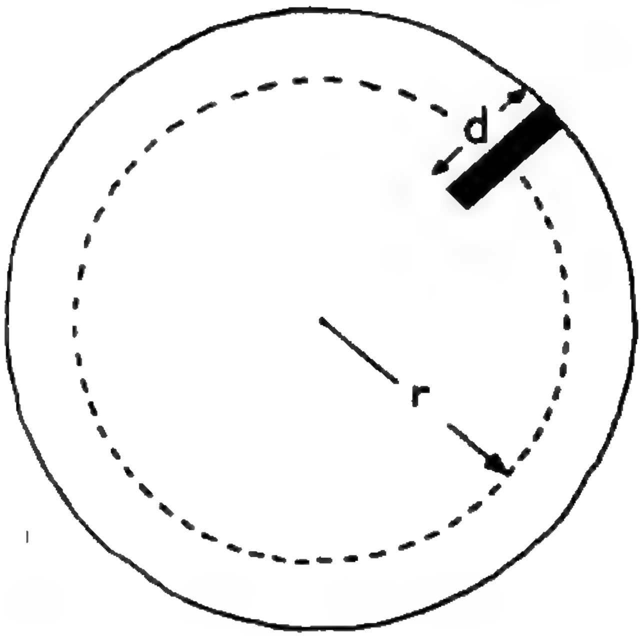
$$\underline{g}_{mod} = -\nabla\phi_{mod} = -\frac{G\,M}{r^2}\left[1 + \alpha\left(1 + \frac{r}{\lambda}\right) e^{-r/\lambda}\right]\hat{r}$$

Therefore

$$g_{mod} = -\frac{M_E\, G_{mod}}{r^2}\,\hat{r}$$

SLIDE 5

Airy's method for determining G



M_E = mass of earth

R_E = radius of earth

d = depth down mine

Assume a spherical, non–rotating earth

At depth $(R_E - r)$ $\qquad g_r = -\dfrac{G\,M}{r^2}$

where $M = \int dM = 4\pi\rho\int_0^r r^2\,dr$

For $r \geqslant R_E$ the free air gradient is

$$\frac{dg_r}{dr} = \frac{2\,G\,M}{r^3} \qquad \text{since} \quad \frac{dM}{dr} = 0$$

However, for $r < R_E$ the gradient is

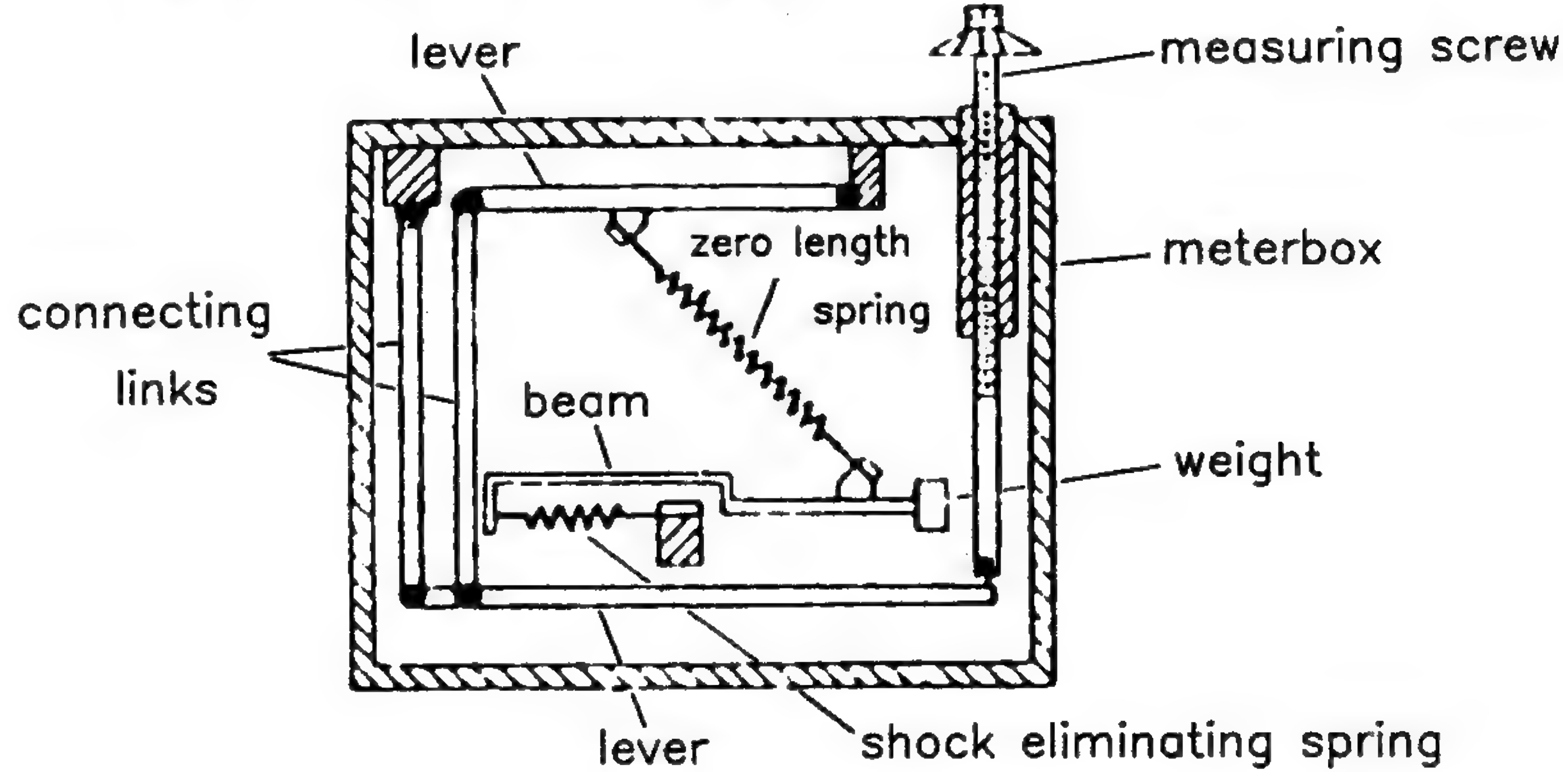
$$\frac{dg_r}{dr} = \frac{2\,G\,M}{r^3} - \frac{G}{r^2}\frac{dM}{dr} = \frac{2\,G\,M}{r^3} - 4\pi G\rho$$

Now $\dfrac{dg_r}{dr} \approx \dfrac{g - g_{R_E - d}}{d}$

Hence $G \approx \dfrac{1}{4\pi\rho d}\left[g_{R_E-d} - g\left(1 - \dfrac{2\,d}{R_E}\right)\right]$

SLIDE 6

The LaCoste & Romberg D – type Gravimeter

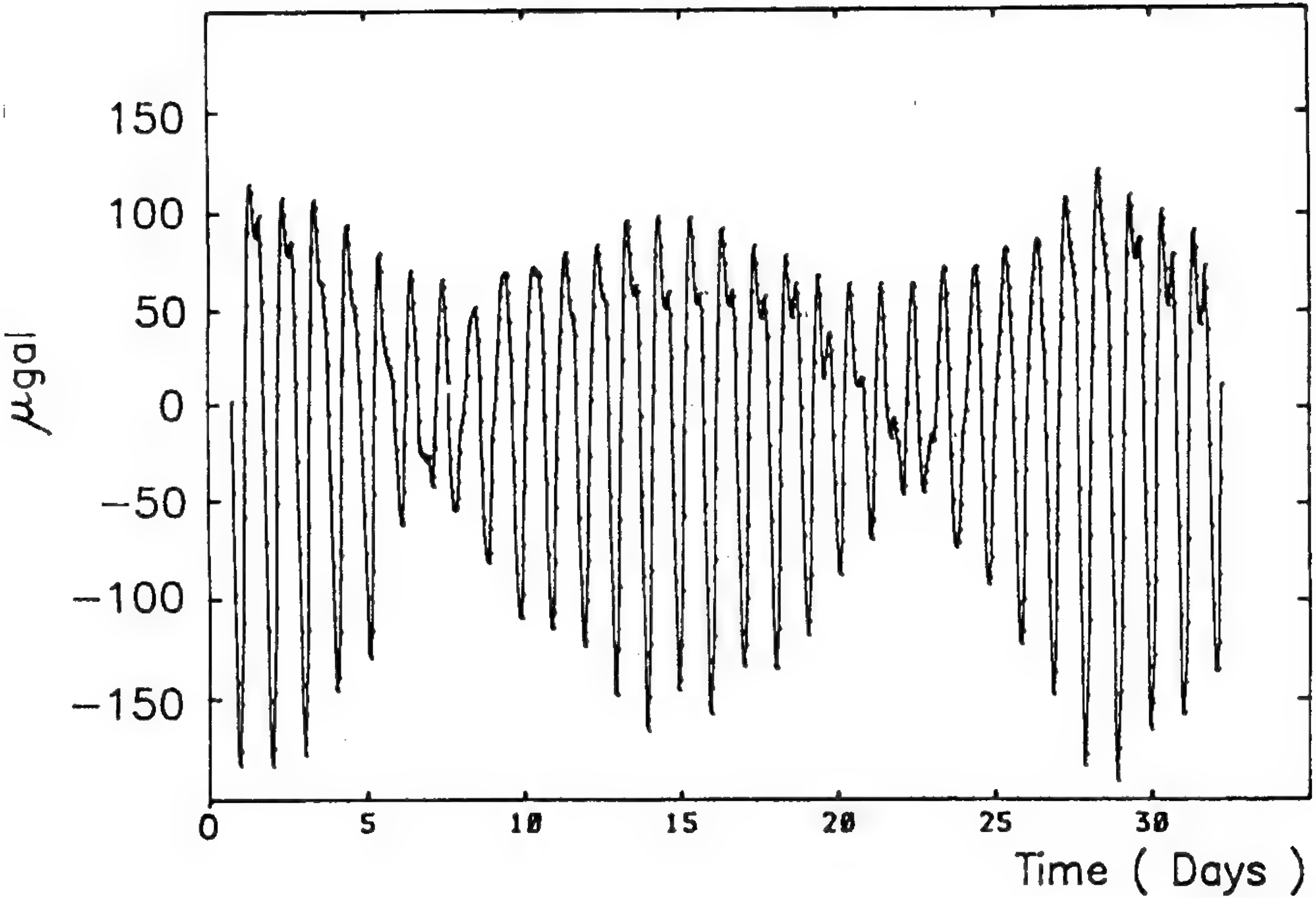


The diagram shows a simplified diagram of the basic LaCoste & Romberg gravity meter. The gravity responsive system consists of a weight on the end of a horizontal beam supported by a zero–length spring. The shock eliminating springs form a floating pivot, thus eliminating any friction in the moving system.

Unit $1\,\mu\text{Gal} = 10^{-6}\,\text{cm s}^{-2}$

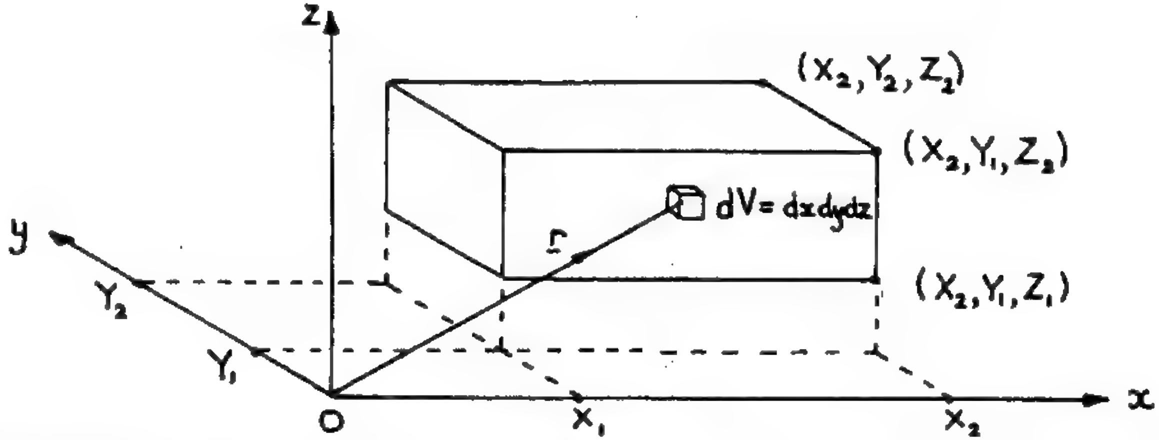
SLIDE 7

The Lunar and Solar Tidal Variations



SLIDE 8

Gravitational Intensity of a rectangular mass block



Elemental mass $dM = \rho dV = \rho(dx\ dy\ dz)$ with pos^n vector $\underline{r} = x\hat{i}+y\hat{j}+z\hat{k}$

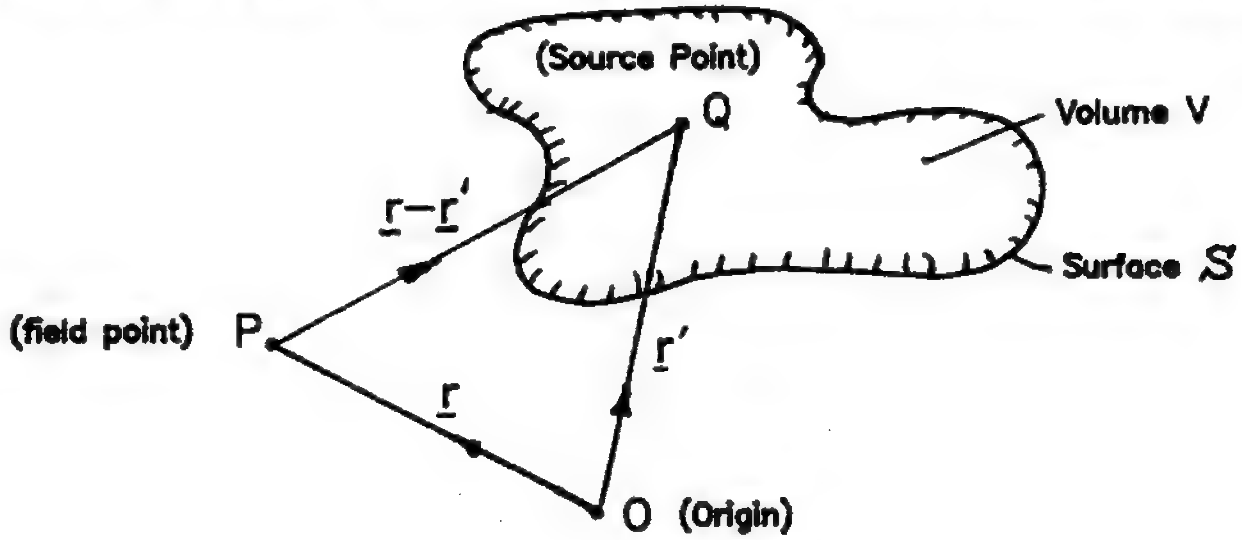
Intensity at O $= -\dfrac{G\ dM}{r^2}\ \hat{r} = -\dfrac{G\rho(dx\ dy\ dz)}{r^3}\ \underline{r}$

Summing for the whole block

Intensity at O $= \underline{g}_{\text{block}} = -G\rho\int_{X_1}^{X_2}\int_{Y_1}^{Y_2}\int_{Z_1}^{Z_2} \dfrac{(x\hat{i} + y\hat{j} + z\hat{k})}{(x^2+y^2+z^2)^{3/2}}\,dx\ dy\ dz$

Vertical component $= g_{z\,\text{block}} = -G\rho\int_{Y_1}^{Y_2} \log\left[\dfrac{X_2+\sqrt{X_2^2+y^2+Z_1^2}}{X_1+\sqrt{X_1^2+y^2+Z_1^2}}\cdot\dfrac{X_1+\sqrt{X_1^2+y^2+Z_2^2}}{X_2+\sqrt{X_2^2+y^2+Z_2^2}}\right]dy$

Gravitational Intensity for a distributed body



In continuous terms, the total potential at P is :–

$$\phi_P = -G \iiint_V \frac{\rho(r')\,dV'}{|\underline{r}-\underline{r}'|}$$

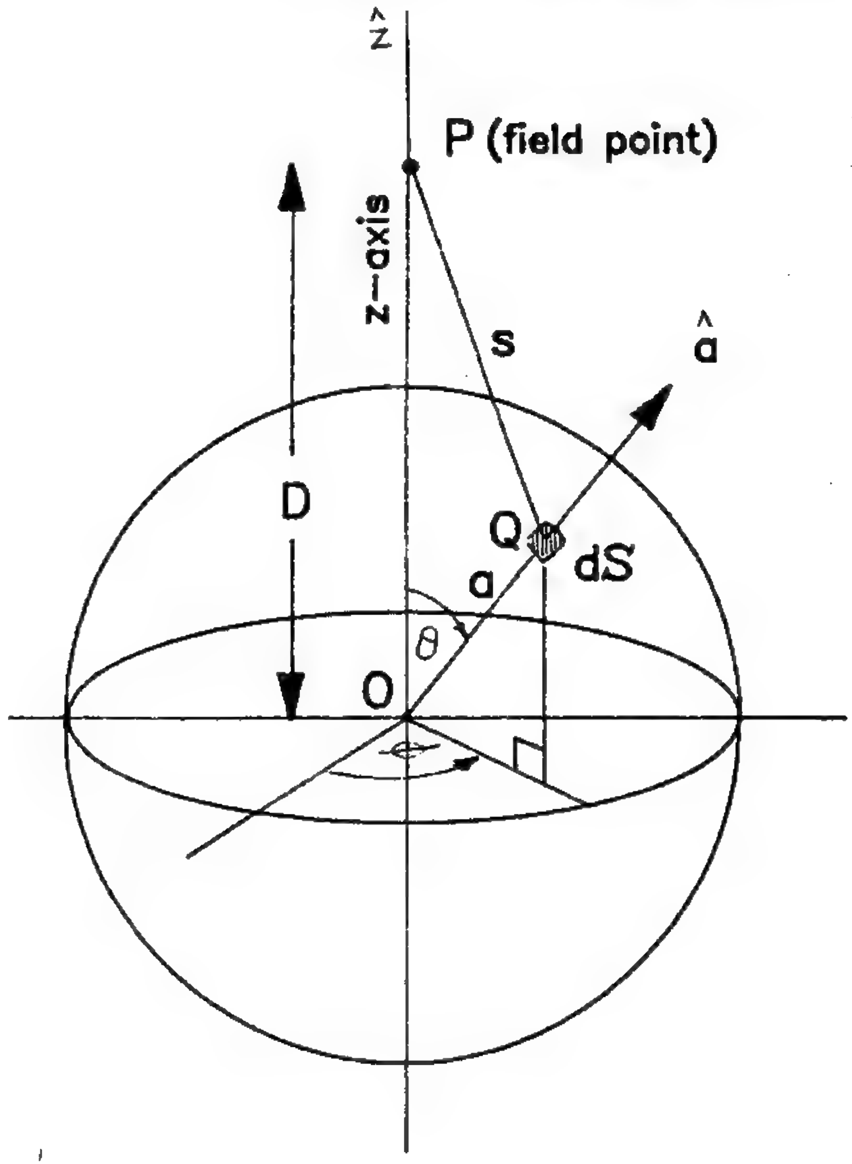
where $\rho(r')$ is the density at any point Q, within V.

Therefore, the gravitational intensity at P is

$$\underline{g}_P = -\nabla\phi_P = G \iiint_V \rho(r')\nabla\left[\frac{1}{|\underline{r}-\underline{r}'|}\right] dV'$$

where order of integration and differentiation can be reversed, since ∇ is a function of $\underline{r}$, not $\underline{r}'$.

The Gravitational Intensity of a Solid Sphere .



Suppose the sphere has radius a

Now $\underline{g}_P = \rho G \iint_S \frac{1}{|\underline{r} - \underline{r}'|} \, \underline{dS}$

therefore, using spherical polars (r, θ, ϕ) :–

$$\underline{g}_P = \rho G \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} \frac{1}{s} (a \, d\theta)(a \sin\theta \, d\phi) . \cos\theta \, \hat{z}$$

since components in other directions cancel.

From the Cosine Rule

$$\cos\theta = \frac{D^2 + a^2 - s^2}{2Da}$$

Changing to s, as the variable of integration.

$$\underline{g}_P = \rho G \, 2\pi a^2 \int_{s=D-a}^{D+a} \frac{1}{s} \left(\frac{s \, ds}{D \, a} \right) \left(\frac{D^2 + a^2 - s^2}{2Da} \right) \hat{z}$$

$$= -\frac{MG}{D^2} \hat{z}$$

where $M = \frac{4\pi a^3}{3}$ is mass of sphere

SLIDE 11

Magnitude of gravitational intensity changes measured at the Dinorwic reservoir

1.	Range of Lunar & Solar Tidal variations	270 μgals
2.	Maximum change of mass of reservoir	80 μgals
3.	Air Pressure changes (Warm & Cold fronts)	1 μgal
4.	Ocean Loading	1 μgal
5.	Lake Loading	$>$1 μgal

The Superconducting Gravity Gradiometer

Mr M Hosey from The Applied Physics Department at Strathclyde University gave us an insight into the use and working of a superconducting gravity gradiometer.

The principle of equivalence states that at any point in space passive gravitational mass is equivalent to active inertial mass. Therefore at any point in space it is not possible to distinguish between an inertial field and a gravitational field. However, over a finite distance, albeit very small, one can determine spatial gradients of acceleration fields. The device used to determine acceleration gradients is called a gradiometer and its use enables one to distinguish between linear and rotational accelerations and gravitational fields (Slide 1).

Theoretically we can consider the 1-D gradiometer as two linear accelerometers, with a common axial direction, fixed a finite distance D apart (Slide 2). The difference in accelerations divided by the baseline D gives the acceleration gradient. By turning the accelerometers by 90° to the baseline D we get another acceleration gradient.

By changing the orientation of the axis the pair of accelerometers can be used to measure 9 possible spatial derivatives of acceleration to form the gradient matrix (Slide 3).

The units of gradiometric measure are Eotvos, where

$$1 \text{ Eötvös} = 10^{-9}\ s^{-2}$$

Usually we only want the gravity gradient matrix, as from this we can estimate the local g-field and hence improve Inertial Navigation (IN) systems.

We can think of an IN system as 3 accelerometers mounted orthogonally on a gyroscopically stabilised platform which remains level with the earth's surface. The output from the accelerometers includes both gravitational and acceleration effects (Slide 4). For most IN systems a simple g-model is provided which enables gravitational effects to be removed from the accelerometer signals. Providing initial velocity and position are known then one integration gives the present velocity, while a second gives the new position. It is estimated that a positional accuracy of better than 100m should be possible, with gradiometer corrected IN in a submarine after an Atlantic crossing.

An improved IN system requires either a better g-model (or perhaps g-map) or some means of measuring the local g-field while moving. If the latter method is chosen then the gradiometer provides the ideal method for measuring local g (Slide 5). To obtain g from the gravity gradient it is necessary to feed back either a current velocity or current position value. However, motion of the accelerometer platform over the earth's surface leads to Schuler errors (Slide 6), since an apparent rotational acceleration comes into play. This effect is overcome by using an externally derived velocity to couple with the gradiometer measurements.

The development of modern gradiometry, during the 1970s, occurred primarily with US Companies (Slide 7), including Hughes Aircraft, Bell Aerospace and the Draper Lab (formerly MIT). In the early 1980s Bell won a US Naval contract to supply a large number of gradiometers for installation in US submarines.

The GPS satellite system has greatly reduced the need to improve commercial airborne IN systems. However, the possibility of satellite destruction in wartime means that the need to provide improved, autonomous IN systems for military aircraft still needs to be assessed.

Geologists, mostly from Petrochemical Companies or Mining Companies, have a great interest in surveying the earth's gravitational field. Any large scale deviation in g from those expected for a slightly ellipsoidal earth of homogenous density are areas which undergo closer scrutiny. Oil fields are usually overlaid with salt domes, which cause characteristic changes in g, while the presence of large deposits of metal ore will clearly cause a local increase in g-value.

In the past, gravitational surveys have been carried out with gravimeters or The Von Eötvös gradiometer. These field measurements are painstakingly slow, since the instruments require a long time to settle down and only spot points are obtained. The advent of the modern gradiometer (Slide 8) offers the possibility of carrying out gravitational surveys from a moving vehicle, since one can separate out the vehicle motion.

Geophysicists have suggested that gravity gradiometers might be used to predict imminent volcanic activity, due to observing local gravity changes caused by magma movement. The possibility that gradiometers might also be used to predict earthquakes by monitoring gravitational changes across fault lines is currently being examined.

For an ideal gradiometer placed in the earth's gravitational field, the measured vertical gradient will be $\frac{d\underline{g}}{d\underline{R}}$, where $\underline{R}$ is a radial vector (Slide 9).

From the inverse square law

$$\frac{d\underline{g}}{d\underline{R}} = \frac{2GM_E}{R^3}\hat{R} = \Gamma_{RR}$$

Near the surface of the earth the gravitational gradient is approximately 3000E.

The gravitational intensity is obtained by integrating with respect to the spatial baseline distance:-

$$g = 2GM_E \int_{R_1}^{R_2} R^{-3}\, dR$$

The study of gradiometry received a further boost when the superconducting accelerometer, with much improved sensitivity, was developed by Paik in the US as part of the instrumentation used in gravitational wave detectors. Cooling the device to very low temperatures meant that the thermal noise level was lowered dramatically. SQUIDS (Superconducting Quantum Interference Devices) with low intrinsic noise properties were then used to obtain large amplification of the accelerometer signal. The sensitivity of the device is limited by the noise introduced by the SQUID.

The device (Slide 10) is cooled to about 4.2°K. At this temperature the niobium proof mass cannot be penetrated by a magnetic field and in effect acts as a ground plane to coil 1 and coil 2.

An initial current I_o is injected into the circuit ABCD which, because of superconductivity, just keeps on circulating without any loss (i.e. current is stored).

Through any loop, enclosing area S, the magnetic flux Ψ is given by

$$\Psi = \int_S \underline{B} \cdot d\underline{S} = LI$$

For a superconducting loop LI = constant, which is an analogue of Ohm's Law. The 3 loops (Slide 11) together with Kirchoff's Law allows the current equations to be solved (Slide 12). Experiment shows that the coil inductances L are proportional to their distances ($d \pm x$) from the niobium proof mass (Slide 13). Thus it is found that the current I_3 sensed by the SQUID is directly proportional to the displacement of the proof mass from its equilibrium position.

We can consider the superconducting accelerometer as an analogue of a mass suspended on a spring, where the magnetic field replaces the spring (Slide 14). Clearly such a system will have a natural resonant frequency ω_o, so that we find

$$I_3 = \frac{2 L_o I_o}{g(L_o + 2L_3)} \cdot \frac{A}{\omega_o^2 d}$$

where A is the acceleration experienced by the device.

Coupling two accelerometers together we can form a 1-D gradiometer (Slide 15), where the SQUID current arises due to difference in acceleration across baseline D. Note the 4 in the denominator is because the inductance L_3 is shared between two systems.

If we introduce an average acceleration $\bar{A} = \frac{1}{2}(A_1 + A_2)$

and a difference in acceleration $\Delta A = A_1 - A_2$

then we can show that by careful choice of the initial input currents I_{10} and I_{20} we can balance out the term containing the average acceleration $\bar{A}$. This just leaves the term containing ΔA (Slide 16).

$$I_3 = \left[\frac{2 L_0}{\eta (L_0 + 4 L_3)} \cdot \frac{I_{10}}{\omega_{10}^2 d_1} \right] \Delta A$$

Hence the acceleration gradient is given by $\frac{\Delta A}{D}$

A 1-D gradiometer has been built and tested at Strathclyde University with funding from ARE. As already mentioned, the device is limited by the noise introduced by the SQUID amplifier. A frequency spectrum of the noise associated with the SQUID shows (Slide 17) that the Strathclyde gradiometer has troublesome resonances near 100Hz, which may be an harmonic of the mains frequency. The device is therefore currently operating under limited bandwidth conditions. Present work is aimed at increasing the bandwidth by employing electronic methods to overcome the resonances. The sensitivity of the device is expected to be between 0.1E and 1E. The aim ultimately of the Strathclyde group is to build a 3-D gradiometer. ARE are continuing to fund the project, while BP are keeping a watching brief.

Looking into the future (Slide 18) one sees that the US has ambitious plans to develop gradiometry. NASA are planning an orbital mission to carry a 3-D superconducting gravity gradiometer. As well as carrying out a gravitational survey there are also plans to use the gradiometer to check Einstein's General Theory of Relativity.

In Europe, ESA are also planning to put a gradiometer into low earth orbit. Apparently the French Government are funding Crouzet to build a gradiometer.

GRAVITY GRADIOMETRY

measuring the difference in weight between two points in Space.

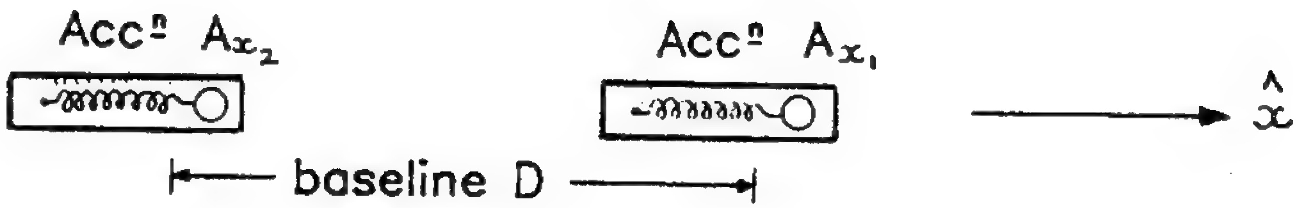
The Principle of Equivalence

At a point in Space one cannot distinguish between a gravitational field and an acceleration.

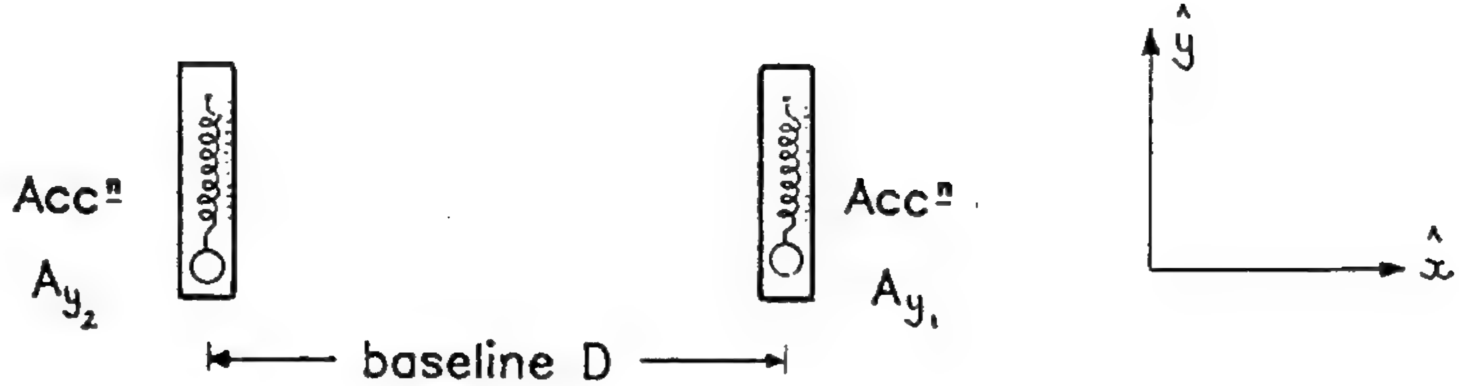
Over a finite distance one can measure the spatial gradient and differentiate between

1. Linear acceleration (zero gradient)
2. Rotational acceleration (constant gradient)
3. Gravitational field (infinite number of derivatives)

Spatial Gradients



$$\text{Spatial Gradient} \quad \Gamma_{xx} = \frac{\partial A_x}{\partial x} \approx \frac{A_{x_2} - A_{x_1}}{D}$$



$$\text{Spatial Gradient} \quad \Gamma_{yx} = \frac{\partial A_y}{\partial x} \approx \frac{A_{y_2} - A_{y_1}}{D}$$

SLIDE 2

The General Gradient Matrix

$$\Gamma = \begin{bmatrix} \frac{\partial A_x}{\partial x} & \frac{\partial A_x}{\partial y} & \frac{\partial A_x}{\partial z} \\ \frac{\partial A_y}{\partial x} & \frac{\partial A_y}{\partial y} & \frac{\partial A_y}{\partial z} \\ \frac{\partial A_z}{\partial x} & \frac{\partial A_z}{\partial y} & \frac{\partial A_z}{\partial z} \end{bmatrix} \quad \text{where } \underline{A} = (A_x, A_y, A_z)$$

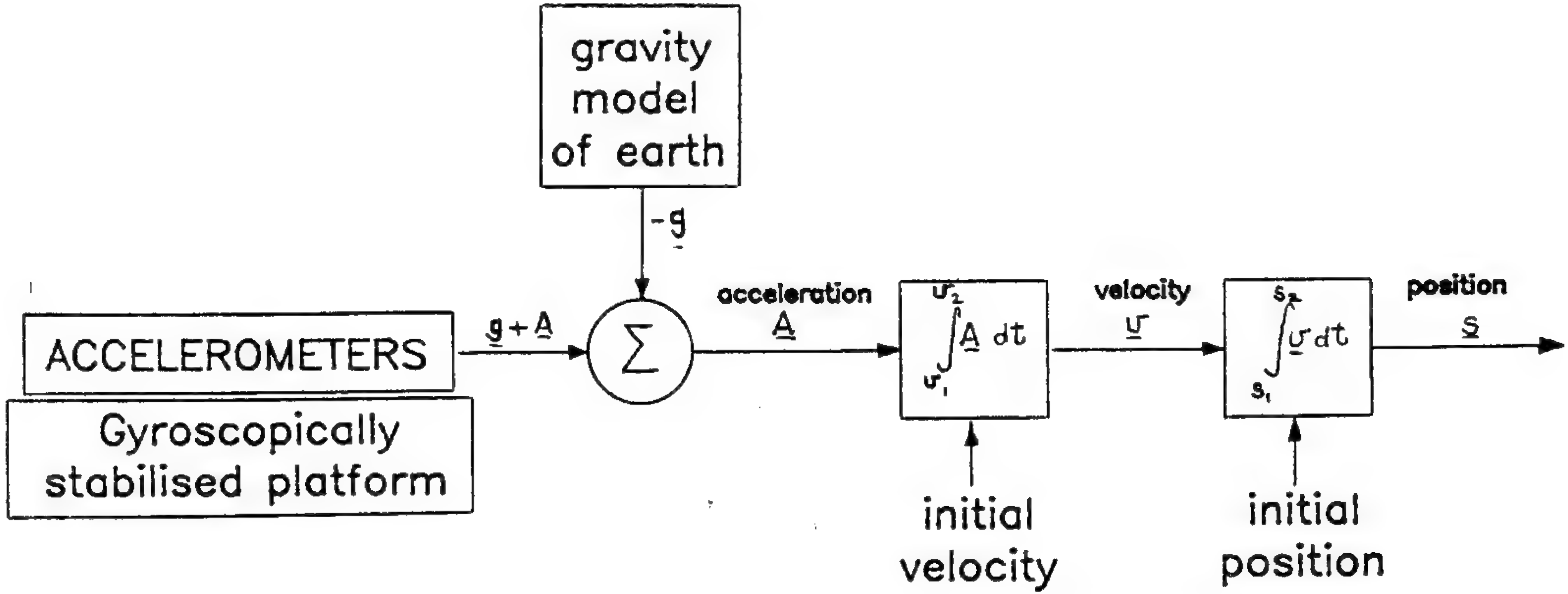
We are usually more interested in the Gravity Gradient Matrix.

This has 9 elements of which only 5 are independent.

Unit 1 Eötvös $= 10^{-9}\ s^{-2}$

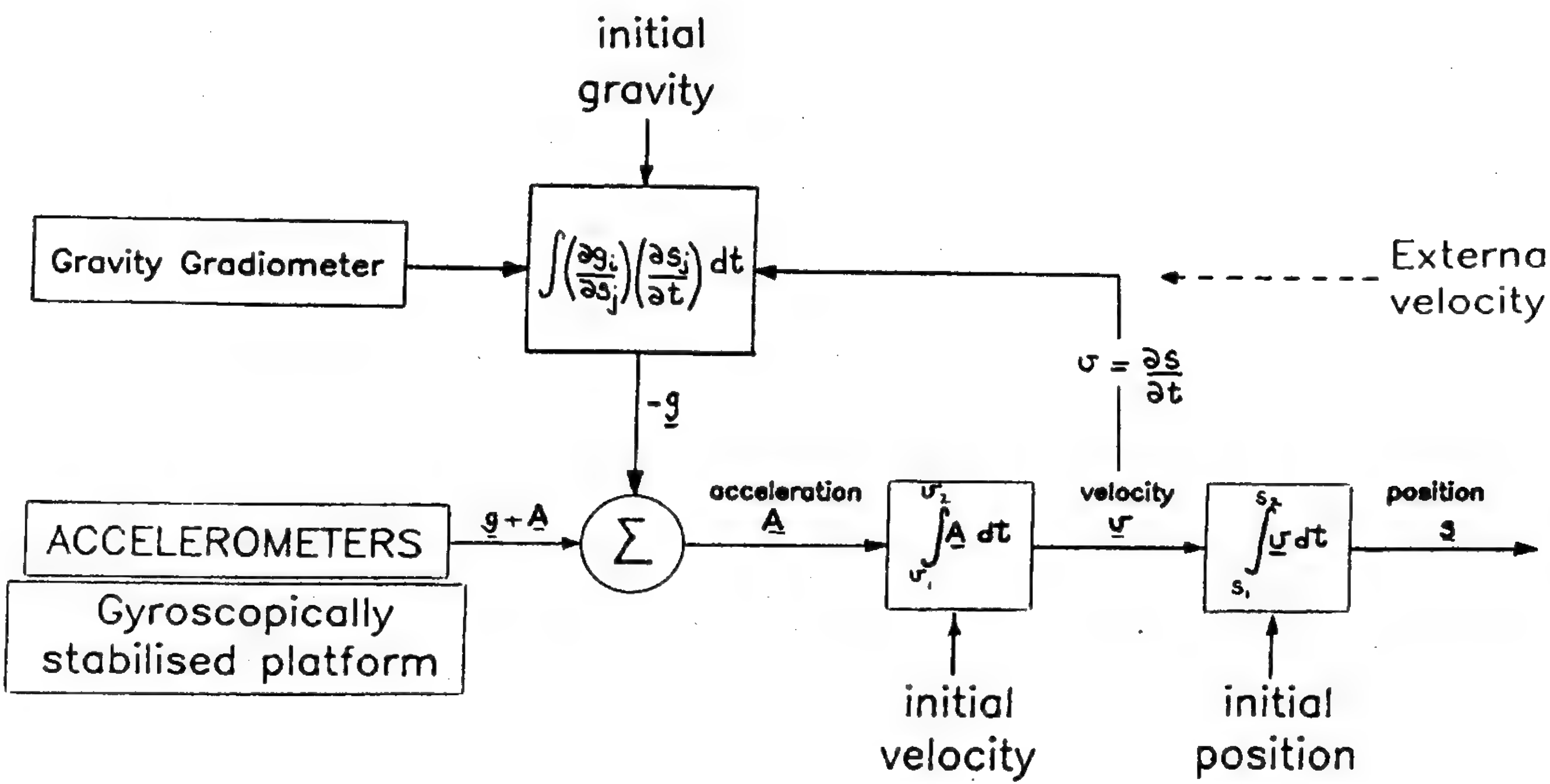
SLIDE 3

Basic Inertial Navigation System



SLIDE 4

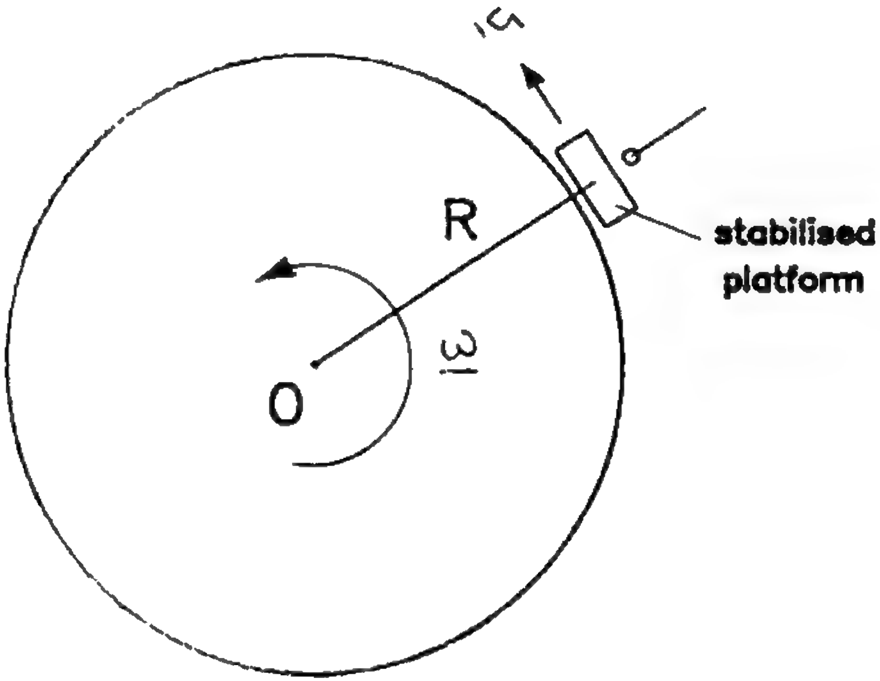
Improved Inertial Navigation System



SLIDE 5

Schuler period

As the stabilised platform moves over the surface of the earth the platform tilts and appears to have an angular velocity $\underline{\omega}$ about o.



$$\underline{v} \equiv R\,\omega$$

Assuming R remains fixed

radial accn = earth's gravitational attraction

$$\omega^2 R = \frac{G\,M_E}{R^2}$$

$$\therefore \quad \omega = \sqrt{\frac{G\,M_E}{R^3}}$$

$$\text{period } \tau = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{R^3}{G\,M_E}}$$

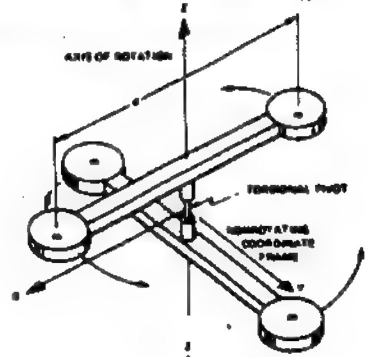
SLIDE 6

On surface of earth $R = R_E$ and $\tau = 84.4$ min.

History of Gradiometry

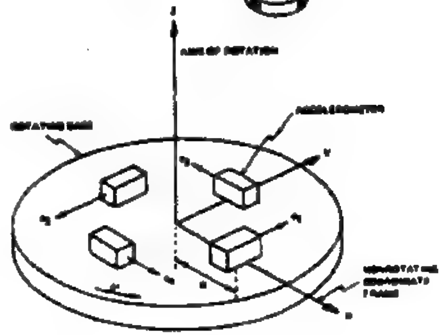
HUGHES AIRCRAFT Co.

Pair of rotating dumbells



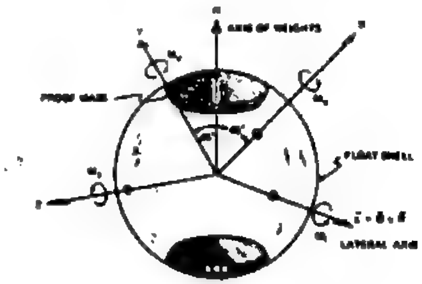
BELL AEROSPACE

Rotating pendulous accelerometers



DRAPER LAB. (MIT)

Electrostatically suspended neutrally buoyant, rotating sphere



Maryland / Stanford Universities

Paik's superconducting accelerometer

— developed for gravitational wave detector

Other uses of Gradiometry

1. Geological Surveys

    Mineral Ores
    Oil fields
    Improved Gravity model

    g – field mapped from moving vehicle

2. Earth surveillance

    Earthquake prediction based on g – measurements at fault line.

    Warning of Volcanic eruption based on g – measurements of Magma movement.

3. Physics Research

    Checking Theory of General Relativity.

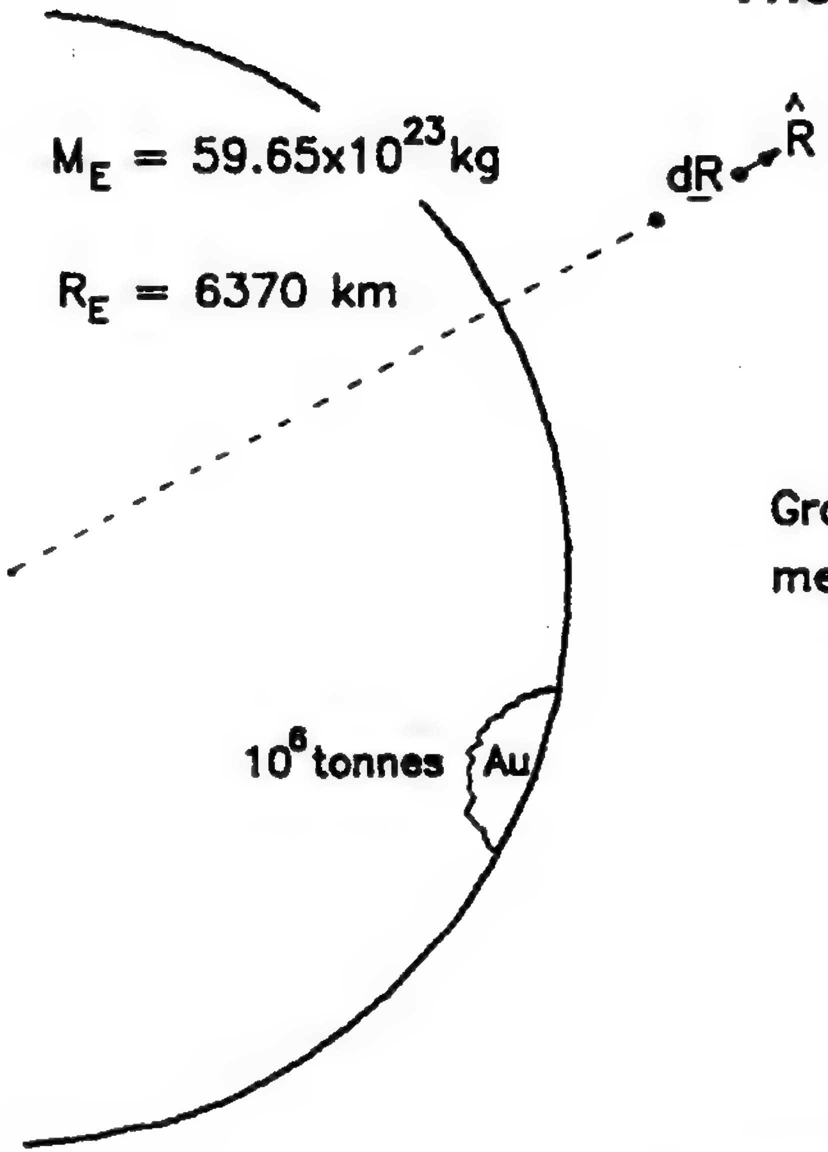
4. Military

    Future developments suggest possible detection of :–

    underwater mines
    submerged subs
    underground buildings
    surface vessels (inc. ships, tanks etc)

SLIDE 8

The Earth



From Newton's Inverse Square Law

Earth's gravitational intensity $= \underline{g} = \dfrac{G\,M_E}{R^2}\,\hat{R}$

Gradiometer measures $\dfrac{dg}{dR} = \dfrac{2\,G\,M_E}{R^3}\,\hat{R} = 3000$ E at surface

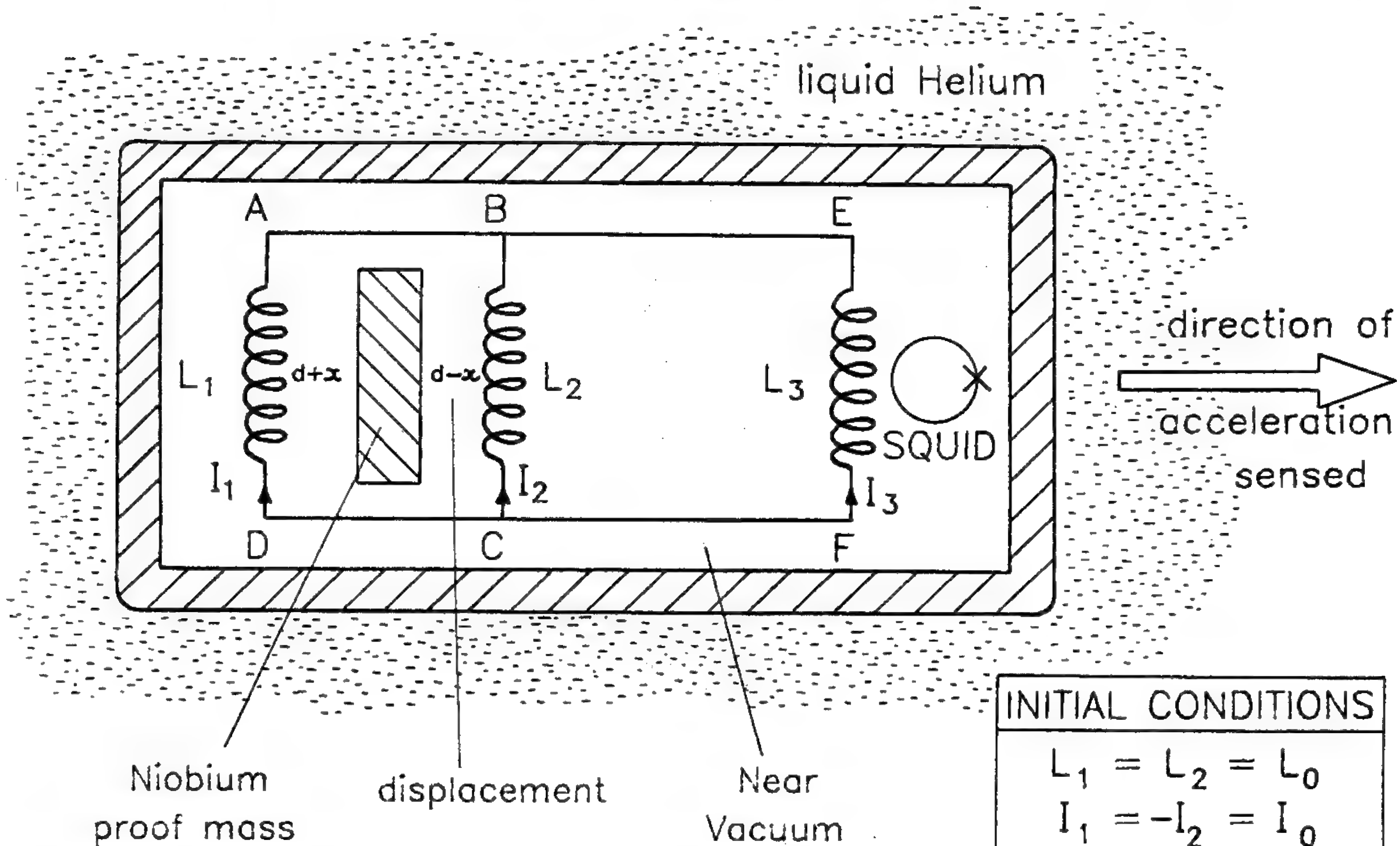
10^6 tonnes of Gold at 1 km = 1 E

$$g = 2\,G\,M_E \int_{R_1}^{R_2} R^{-3}\,dR$$

ie One integration wrt spatial baseline direction gives g

SLIDE 9

A Superconducting Accelerometer



INITIAL CONDITIONS
$L_1 = L_2 = L_0$
$I_1 = -I_2 = I_0$
$x = 0$

SLIDE 10

Analogue of Ohm's Law

Magnetic Flux $\Psi = \int_S \underline{B} \,.\, d\underline{S} = L\,I =$ constant for a loop.

Loop ABCD

$$L_1 I_1 - L_2 I_2 = \Psi_{ABCD} = 2\, L_0 I_0 = \text{constant} \qquad (1)$$

Loop AEFD

$$L_1 I_1 - L_3 I_3 = \Psi_{AEFD} = L_0 I_0 = \text{constant} \qquad (2)$$

Loop BEFC

$$L_2 I_2 - L_3 I_3 = \Psi_{BEFC} = L_0 I_0 = \text{constant} \qquad (3)$$

Total flux in a superconducting loop is constant.

Solving for Currents

Eqns 1, 2 & 3 give singular soln.

Need another eqn. Kirchoff's Law $I_1 + I_2 + I_3 = 0$ (4)

Use eqns 1, 2 & 4

$$\begin{bmatrix} L_1 & -L_2 & 0 \\ L_1 & 0 & -L_3 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = L_0 I_0 \begin{bmatrix} 2 \\ 1 \\ 0 \end{bmatrix}$$

Inverting Coefficient Matrix

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = L_0 I_0 . \frac{1}{L_1 L_2 + L_3(L_1 + L_2)} . \begin{bmatrix} L_3 & L_2 & L_2 L_3 \\ -(L_1 + L_3) & L_1 & L_1 L_3 \\ L_1 & -(L_1 + L_2) & L_1 L_2 \end{bmatrix} \begin{bmatrix} 2 \\ 1 \\ 0 \end{bmatrix}$$

Current sensed by SQUID

$$I_3 = \frac{L_0 I_0}{L_1 L_2 + L_3(L_1 + L_2)} (L_1 - L_2)$$

Experiment shows inductance $\propto$ to distance from niobium proof mass

$$L_1 = L_0(1 + \frac{x}{\eta d}) \quad \text{and} \quad L_2 = L_0(1 - \frac{x}{\eta d})$$

where η = constant of proportionality

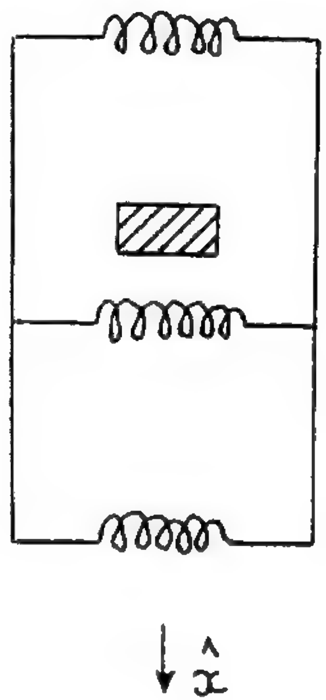
Substituting :–

$$I_3 = \frac{2 I_0}{\eta(L_0 + 2L_3)} \left(\frac{x}{d}\right)$$ to 1^{st} order in $\left(\frac{x}{\eta d}\right)$

Sensed current proportional to proof mass displacement

SLIDE 13

Resonant Frequency



The accelerometer is analagous to a mass suspended from a spring, where the magnetic field replaces spring.

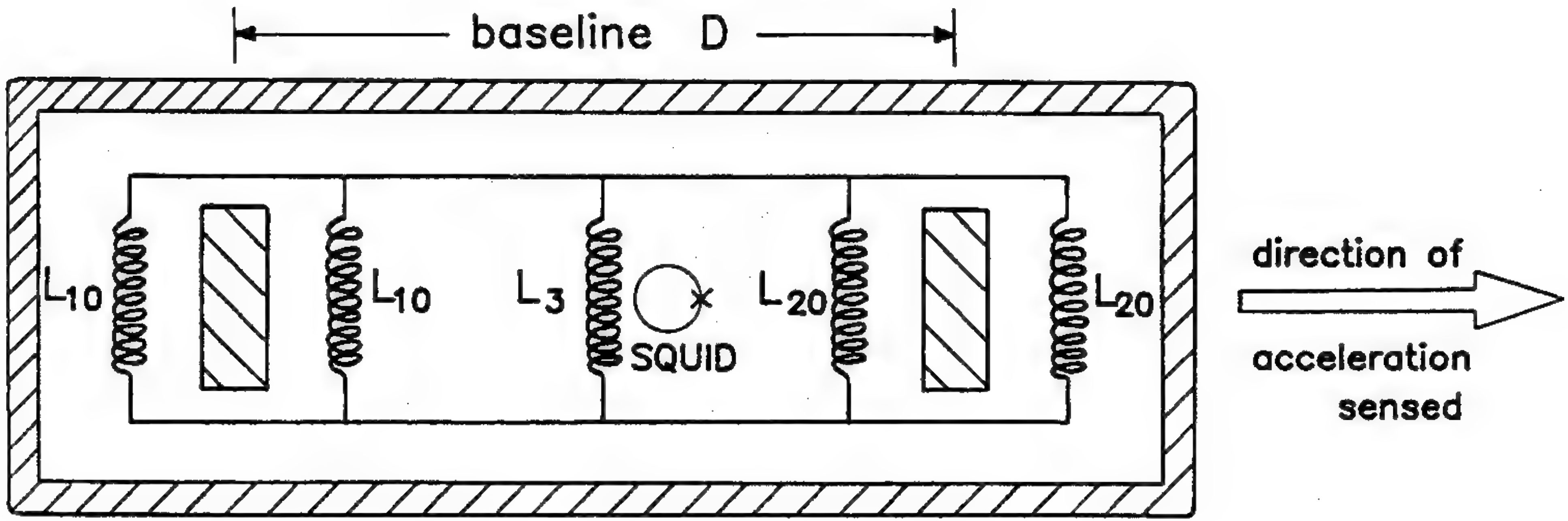
SHM $\quad \ddot{x} + \omega_o^2 x = 0$

Hence

$$I_3 = \frac{2 L_0 I_0}{\eta (L_0 + 2 L_3)} \cdot \frac{A_x}{\omega_o^2 d}$$

where accn $A_x = |\omega_o^2 x|$

The 1 – Dimensional Superconducting Gradiometer



Current sensed by SQUID

$$I_3 = \frac{2\,L_0}{\eta(L_0 + 4L_3)}\left[\frac{I_{10}A_{x_1}}{\omega_{10}^2 d_1} - \frac{I_{20}A_{x_2}}{\omega_{20}^2 d_2}\right]$$

assuming $L_{10} = L_{20} = L_0$

SLIDE 15

Balancing the Gradiometer

Let average acceleration $\bar{A}_x = \frac{1}{2}(A_{x_1} + A_{x_2})$

& difference in acceleration $\Delta A_x = A_{x_1} - A_{x_2}$

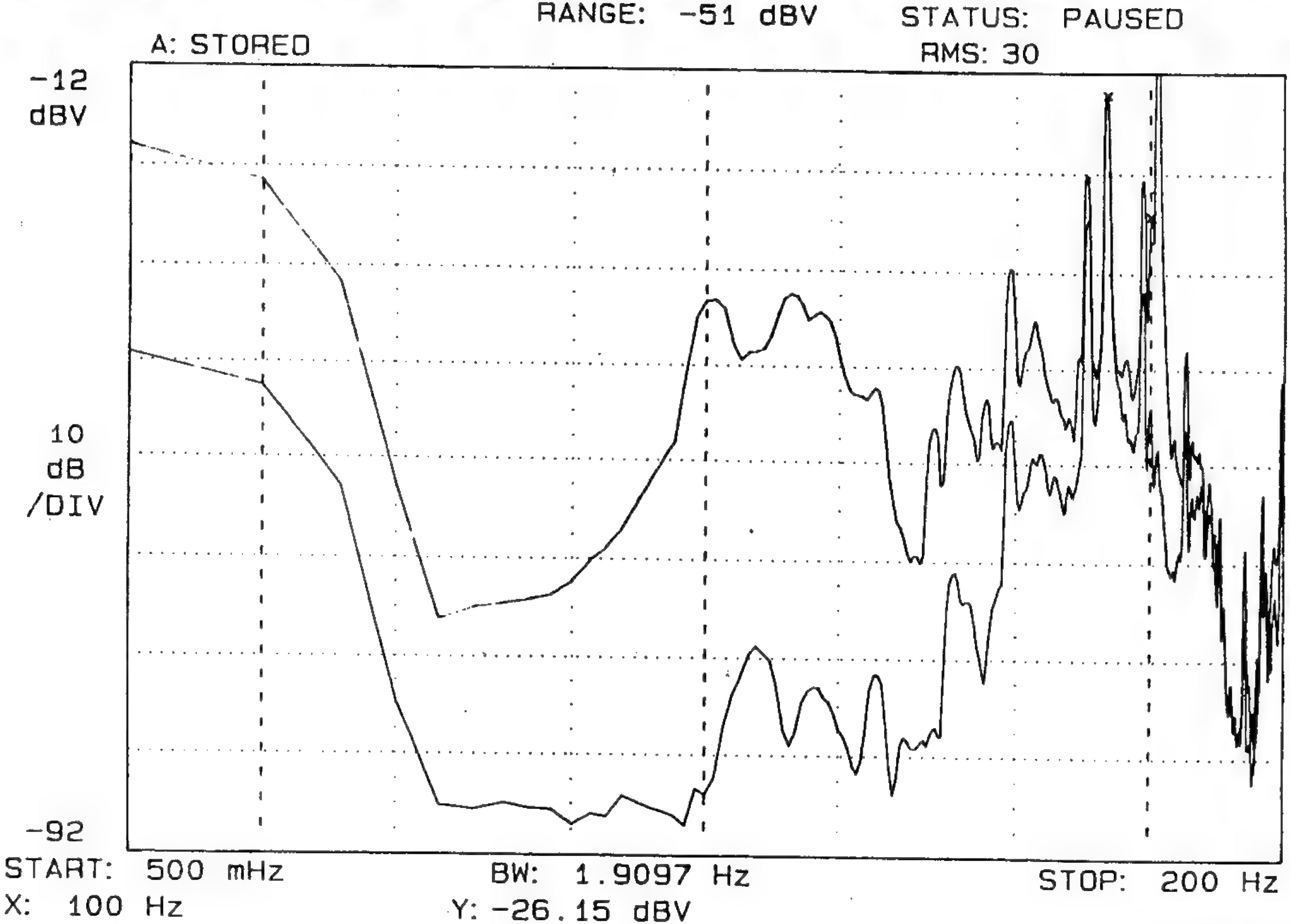
Substituting

$$I_3 = \frac{2\,L_0}{\eta(L_0 + 4L_3)} \cdot \left\{ \underbrace{\left[\frac{I_{10}}{\omega_{10}^2 d_1} - \frac{I_{20}}{\omega_{20}^2 d_2} \right] \bar{A}_x}_{\text{balance out}} + \left[\frac{I_{10}}{\omega_{10}^2 d_1} + \frac{I_{20}}{\omega_{20}^2 d_2} \right] \frac{\Delta A_x}{2} \right\}$$

$$I_3 = \left[\frac{2L_0}{\eta(L_0 + 4L_3)} \cdot \frac{I_{10}}{\omega_{10}^2 d_1} \right] \Delta A_x$$

Hence $\Gamma_{xx} = \frac{\partial A_x}{\partial x} \approx \frac{\Delta A_x}{D}$ is determined.

SLIDE 16


RANGE: -51 dBV
STATUS: PAUSED
RMS: 30
A: STORED
-12
dBV
10
dB
/DIV
-92
START: 500 mHz
X: 100 Hz
BW: 1.9097 Hz
Y: -26.15 dBV
STOP: 200 Hz

SLIDE 17.

The Future

NASA

Superconducting 3–axis gravity gradiometer for orbital mission.

Projected sensitivity 10^{-3} E

Funding : USAF, US Army

ESA

Aristoteles – Earth Resources Programme.

Gradiometer in low earth orbit.

Funding : French Govt (?) –– Crouzet (Joint Venture Co. Thompson CSF & Aerospatial)

STRATHCLYDE

Work progressing – leading eventually to 3–axis gradiometer

Expected sensitivity 0.1E – 1 E

Funding : ARE (BP keeping a watching brief)

A Reminder of Faraday's Gravitational Experiments

Michael Faraday had great insight into the workings of Nature and I feel it may be a useful introduction to today's discussion, which is aimed at speculative experiments which might demonstrate a link between gravity and electromagnetism, to remind ourselves of Faraday's original gravitational research.

Faraday's view of the Creation was that all forces stemmed from a single source (Oersted had expounded this philosophy earlier) and that consequently all forces were mutually convertable. Slide 1 shows the famous passage from his diary, first suggesting the possibility that gravitation and electromagnetism might be linked. Faraday spent 10 years searching for the key to their relationship, but without success. By today's standards, Faraday's experiments appear rather crude, but a similar approach had already enabled him to discover the phenomenon of electromagnetic induction. As we know now, electrical forces are of order 10^{40} times greater than gravitational forces so the odds on him discovering anything were minimal. But what of his ideas?

In Faraday's first gravitational experiment (Slide 2), he placed a coil around a mass rod (samples used were copper, bismuth, iron) and this combination was allowed to fall in the earth's gravitational (& magnetic) field.

In trying to ascertain his thoughts behind this experiment, a further quote from his diary (Slide 3) is relevant, where he asks, "what is the dual of Gravity?". At first sight, he seems to be suggesting the existence of an unknown force field associated with inertia. Similar thoughts today have suggested the possible existence of a gravito-magnetic field, being the inertial analogue of magnetism. However, after further reading, it seems clear that he expected electricity to be the dual of gravitation. This latter idea fits in directly with his thoughts on unification and, as a strict Sandeman, he may have been aware of the basic cabalistic philosophy of the triad of forces.

Note that in his experiment, the mass did not cut lines of gravitational force but fell along a line of force. The analogue is, surely, an electric charge being accelerated in an electric field. Relative to a fixed observer, the passing electric charge appears to have developed a magnetic field.

But what was Faraday's thought?

According to his diary, he felt that as the mass accelerated it would develop surface electric currents rotating about an axis coincident with the direction of fall. The transient magnetic field, associated with any incipient surface currents, would induce a current in the surrounding coil, which could be detected by the galvo.

After being careful to avoid any current being induced in the trailing wires to the galvo as they fell through the earth's magnetic field, he showed that no current was induced by the falling body.

But the coil was fixed relative to the body!

Why did Faraday choose not to cut lines of gravitational force in his experiment? After all, he was always looking for natural phenomena as a guide in his experimental quests. As his diary shows, he did wonder about the origin of the earth's magnetic field. The earth, as it free falls in its orbit, cuts the sun's gravitational lines of force.

Now although Faraday's first experiment was unsuccessful, he did not discard his previous idea that electricity was the dual of gravitation; rather he considered how he might increase the size of any effect. Perhaps, he thought, a mass rapidly accelerating to and fro might cause alternating surface currents to arise. His apparatus to investigate this idea is shown in Slide 4. By turning the great wheel, the V-shaped arm was made to vibrate through about 3 inches. Fitted between the ends of the arms was a mass rod (samples were copper, bismuth, glass, sulphur, gutta percha) which oscillated to and fro through the fixed coil. This time there was relative motion between the mass and the coil. The commutator would have allowed any alternating current which developed, to be summed. But again, no effect was detected.

Faraday then reconsidered his ideas. He was still of the opinion that gravity and electricity were somehow related, but he wondered whether heat might provide the connecting link. The analogue of Joule heating of a wire by the passage of electric current is the increase in temperature of a mass falling with a terminal velocity through a gravitational field.

To investigate this idea, Faraday used the Shot Tower in London (Slide 5). A series of experiments were performed which involved raising and lowering a mass of mercury and checking for any internal temperature change as the gravitational PE of the mass altered. Slide 6 shows the two ways in which Faraday attempted to do this. Initially he used the Casella mercury thermometer, containing about 1lb of mercury. The thermometer was raised and lowered 165ft within the Shot Tower and the temperature monitored at the top and bottom of the traverse. However, no change in temperature due to gravitational effect was observed.

To improve the sensitivity of the temperature measurements, a differential air thermometer was used in conjunction with just over 2lb of mercury. The experimental procedure was repeated, but again no effect was observed.

Faraday's final thought on the subject was that, although continuous surface currents didn't appear to arise, perhaps a mass developed an electrostatic charge as it underwent a gravitational change.

In his last experiment, a mass was raised and lowered within the Shot Tower and checks were made to see whether it developed an electric charge as its gravitational PE changed. Initially Faraday employed a 170lb pig of lead (Slide 7) but this was later supplemented with another, giving a total mass of 280lb.

Faraday tackled the experiment in two ways. Firstly the masses were charged at the bottom of the tower. Platinum wires connected the masses to an electrometer, so that any changes in charge could be observed. The masses were then raised to the top of the tower. No change in charge was observed. The procedure was then reversed, the masses being discharged at the bottom of the tower, raised to the top and checked to see whether a charge had developed. But again a null result.

Although Faraday was baffled, he remained convinced that gravity and electromagnetism were somehow connected. Einstein was of the same opinion and many other scientists concur. But so far no link has been found.

Since Faraday's time, two further fundamental forces have been discovered. These are the strong and weak nuclear forces which operate over microscopic ranges within the atom. Unification between electromagnetism and the weak nuclear force has already been demonstrated. The search for a link between electromagnetism and gravity continues.

One of the prime objectives of this Round Table Meeting is to try to formulate some experiments, naturally speculative, which might be worth carrying out as part of this Search.

We realise that this is a most difficult and challenging task, but BAe are keen to nurture this activity.

Let us hope that Serendipity is kind to us.

The Unification of Gravitation with Electromagnetism

par: 10018 "Gravity. Surely this force must be capable of an experimental relation to Electricity, Magnetism and the other forces, so as to bind it up with them in reciprocal action and equivalent effect. Consider for a moment how to set about touching this matter by facts and trial."

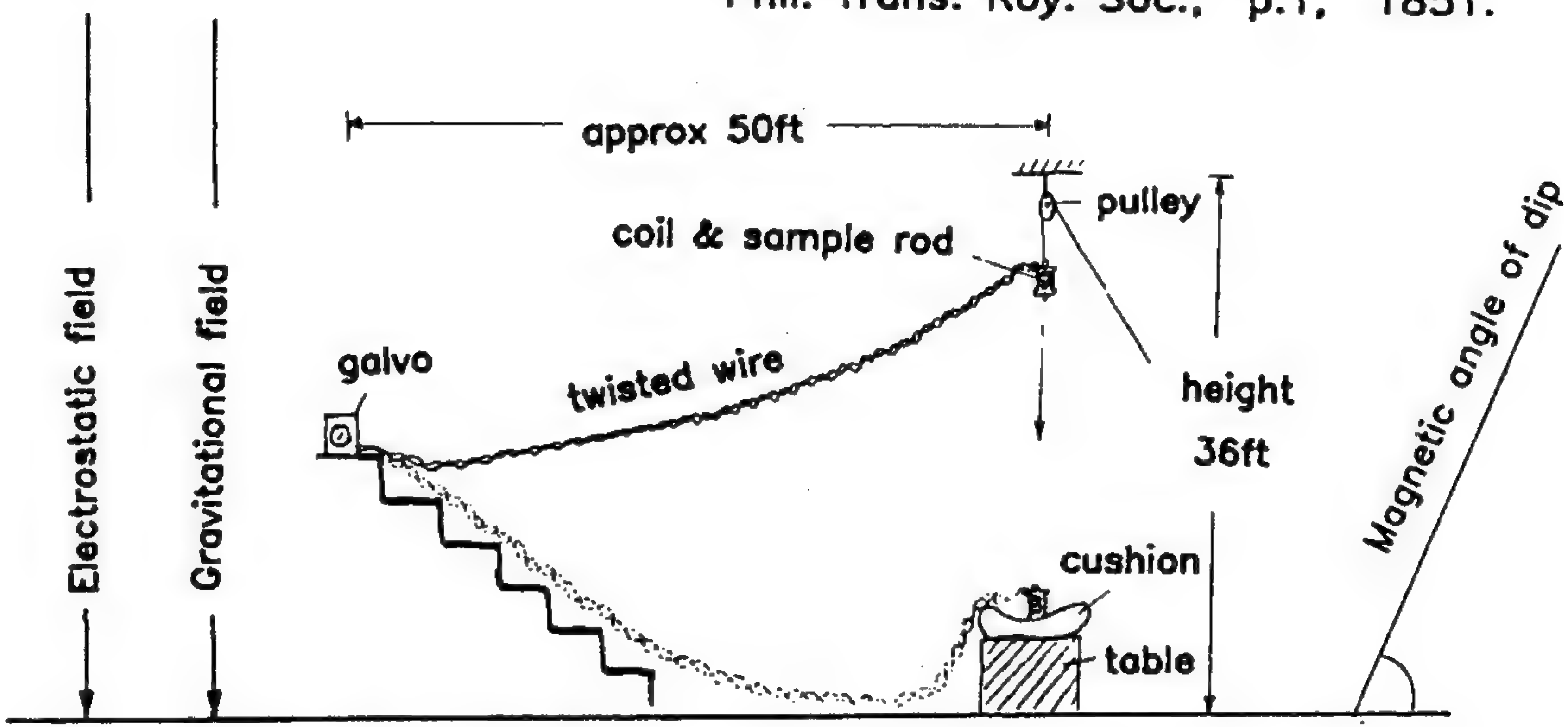
19th March 1849

Faraday's Diary.

SLIDE 1

2704. The thought on which the experiments were founded was, that, as two bodies moved towards each other by the force of gravity, currents of electricity might be developed either in them or in the surrounding matter in one direction; and that as they were by extra force moved from each other against the power of gravitation the opposite currents might be produced.

Phil. Trans. Roy. Soc., p.1, 1851.



Floor of the Lecture Room at the Royal Institution.

SLIDE 2

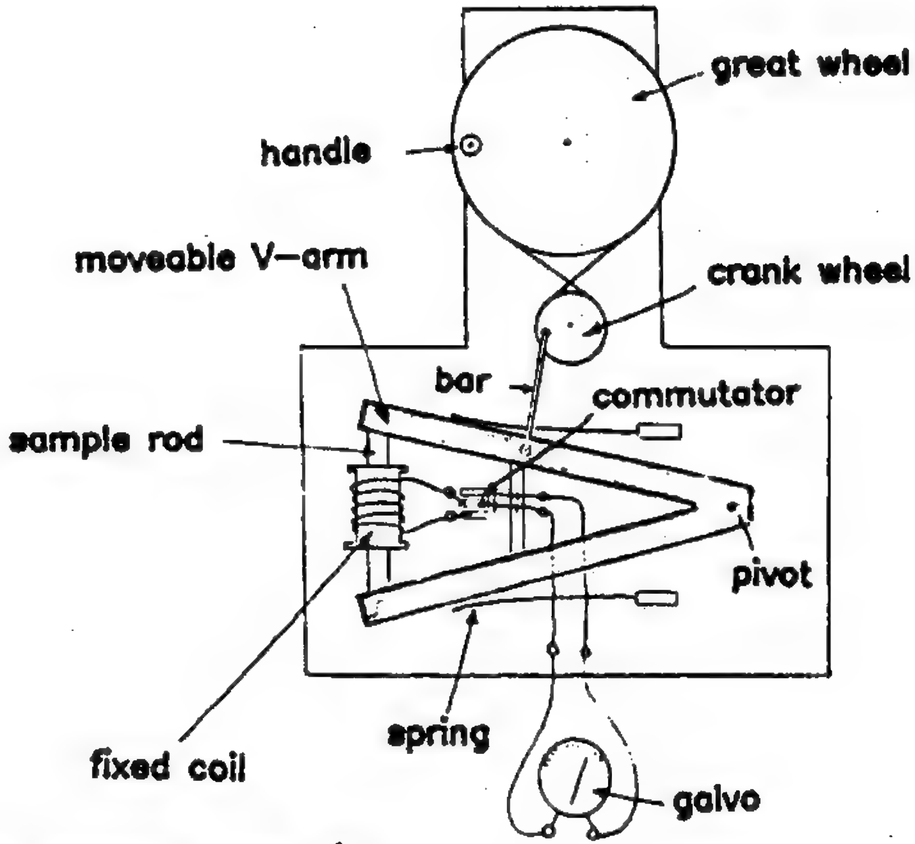
Does Gravity have a dual force ?

Par: 10019 "What in Gravity answers to the dual or antithetical nature of the forms of force in Electricity and Magnetism ? Perhaps the to and and fro, that is, the ceeding to the force or approach of Gravitating bodies, and the effectual reversion of the force or separation of the bodies, quiescence being the neutral condition".

19th March 1849
Faraday's Diary

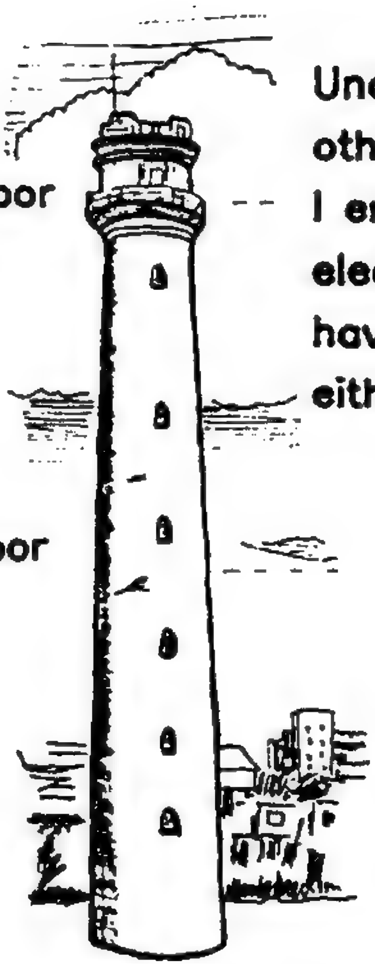
SLIDE 3

Having shown that a body falling through a gravitational field does not produce a continuous electric current, Faraday considered the possibility that a body rapidly accelerating to and fro might cause a discontinuous electric current, analagous in some respects to his law of electromagnetic induction.



516ft of covered copper wire

SLIDE 4



Note on the Possible Relation of Gravity with Electricity or Heat.

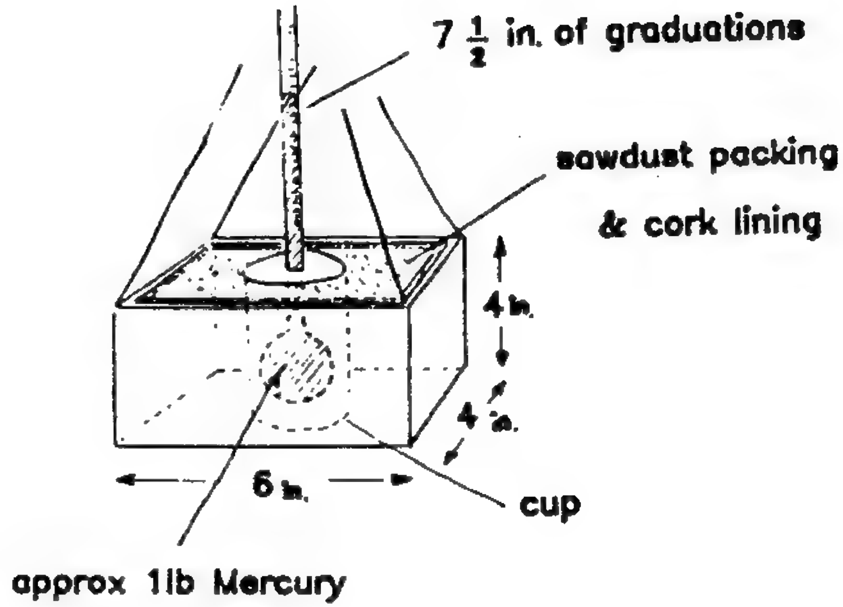
Under the full conviction that the force of gravity is related to other forms of natural power, and is a fit subject for experiment, I endeavoured on a former occasion to discover its relation with electricity, but unsuccessfully. Under the same deep conviction, I have recently striven to procure evidence of its connection with either electricity or heat.

Unpublished paper April 1860.

The Shot Tower   South Bank (near Waterloo Bridge), London.

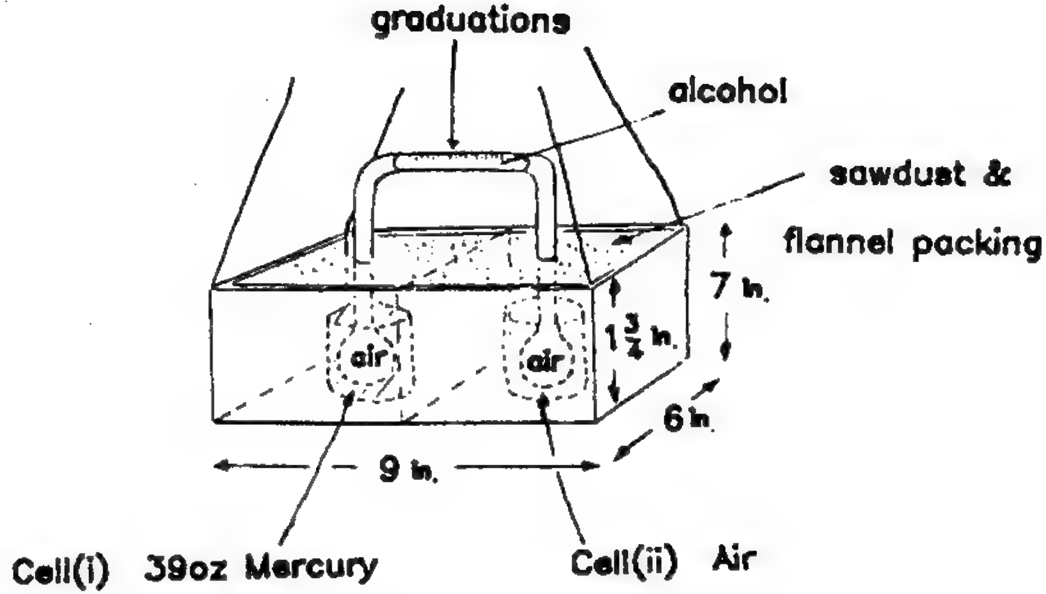
Built in 1826. Demolished in 1963.

SLIDE 5



(Total Weight 5 1/4 lbs)

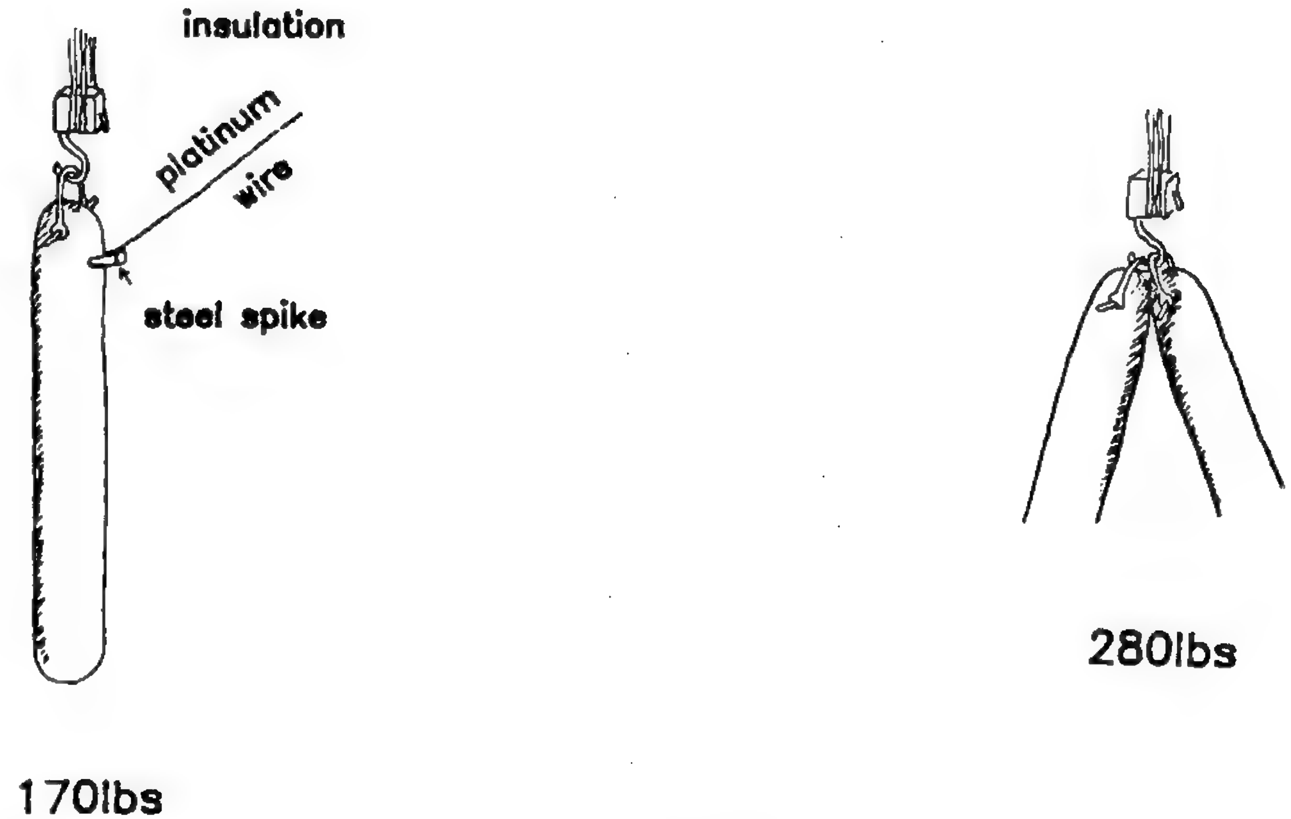
Casella's Mercury Thermometer



(Total Weight 10lbs)

Differential Air Thermometer

SLIDE 6



pig of lead

SLIDE 7

<u>Review of Microgravity</u>

Dr Anders Hansson, a theoretical physicist, was a member of The Peer Review Group and one of the three project scientists working on the Juno Mission, where his special interest was in microgravity experiments.

Anders began his review of microgravity by suggesting that biological experiments might be developed to provide early indicators of quantum effects in microgravity (note attached). In particular, gravity sensing with plants has been considered.

He then discussed Puthoff's interpretation (ref. 1) of Andrei Sakharov's idea that gravity might be due to an induced effect brought about by quantum fluctuations of the Vacuum (the Ether?) due to the presence of matter, rather than as an inherent property of the matter itself. This conflicts with Einstein's view that energy is a source of mass and that mass is the source of gravity. Anders mentioned the claim by Russian scientists, that Einstein's formula for gravitational radiation is not a consequence of the General Theory of Relativity (ref. 2).

By quantum fluctuations of the Vacuum is meant that space is not empty but seething with randomly fluctuating electromagnetic fields (and presumably gravitational fields too) which contain virtual electron-positron pairs with infinite self-energy, even at absolute zero on the temperature scale. This zero point energy (ZPE) is associated with all four fundamental forces of nature.

Dr Hansson has written several papers speculating on the possible use of Vacuum energy as a means of propulsion for future interstellar space travel (refs. 3 & 4). It has been suggested that the reason that the speed of light in a Vacuum is finite is that as light propagates through space there is a continual interaction between the carrier photons and the virtual (very short-lived) electron-positron pairs. The absorption and re-emission of the photons not only takes time, but gives rise to the permittivity ε_0 of free space.

One observable feature arising from fluctuations of the Vacuum is the Casimir, or Van der Waals, force (ref. 5). This is an attractive force that appears between two closely spaced (of order $1\mu m$), uncharged parallel plates made of electrically conducting material. This attraction, which is a sort of surface tension effect of Vacuum, implies that the ZPE between the plates has decreased.

The theory of Quantum Electrodynamics (QED) treats the interactions between all charged particles in terms of the exchange of virtual photons. In QED the infinite energies (and infinite speeds) are deliberately avoided by introducing a renormalisation procedure. (NB. A vector field can be derived from an infinite number of potentials, which all differ by a constant). The sizes of the masses and charges of the interacting particles are redefined using experimental values. In this way, QED has been successfully used to unify theoretically the electromagnetic and the weak nuclear forces (ref. 6).

Nevertheless, some scientists are sceptical of the renormalisation technique and attribute a real meaning to the predicted enormous zero point energies. Whereas the presence of gravitational and electromagnetic fields can be directly observed macroscopically due to the forces involved, the evidence for the weak nuclear force field is associated with beta (β) - decay, a type of radio-activity exhibited by some unstable nuclei. In β - decay a neutron, by emitting an electron and an anti-neutrino, turns into a proton.

Theory suggests that β - decay occurs in the nuclear reactions taking place at the centre of stars and in supernovae. Because neutrinos only interact very weakly with matter they are extremely difficult to detect. The electrons produced in β - decay are easily detected since they interact more strongly with matter, via the electromagnetic force.

The theoretical description of the weak force field currently being developed is fairly complicated, including such phenomena as symmetry breaking which characterises the weak field. Dr Hansson made reference to Professor Davies' books on the new physics (e.g. Ref. 7).

In terms of QED, the carriers of the weak force are the W and Z particles first observed in the particle collider at CERN in 1983.

Dr Hansson ended his talk with the mention of the prigogine crystal (note attached), which is a special crystal which may be developed to try to reveal the presence of an intermediate force field (Higgs?) which is thought to arise during the interaction of the weak and electromagnetic force fields. It would be an advantage to carry out any experiments in a microgravity environment to avoid vibrational effects.

Although ideas are still being formulated it seems that the experiments envisaged could be carried out at room temperature and would not require the symmetry breaking temperatures associated with star cores.

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QUANTUM EFFECTS IN MICROGRAVITY IS BIOLOGY AN EARLY INDICATOR?

P A HANSSON - Commercial Space Technologies Ltd

ABSTRACT

The quality of microgravity required to investigate different processes varies. A simple calculation shows a wide range of required 'g-force' from 10^{-3} to 10^{-5} for glasses and ceramics 10^{-7} through 10^{-9} for quantum fluids and to 10^{-9} to 10^{-12} for gravitational physics.

Since 'weightlesness' occurs when the gravitational force vector is counter balanced by the centrifugal force imparted by a spacecraft as it travels tangentially to the surface of a planet it can be shown that the optimal 'weightlessness' requires an orbit with a radius of 1.5 radii of the central body. For the Earth, this is 2,800 km which is in a zone of strong radiation, and for the sun it is too close. For the Moon, the optimum 'weightlessness' is a 800 km orbit from its surface and the microgravity level there is 1,000 times closer to zero than in LEO.

It is obvious that such an orbit offers opportunities for scientific and technical advances for testing fundamental theories like quantum physics. A realistic approach to this demands analysis and planning, and biological experiments might enable certain aspects of theories to be tested before the design of a quantum fluid testbed.

It is possible that the interaction in microgravity is a quantum reasonance and that in biological processes this is enhanced due to:

* Water structure
* Thiols (SH S-S bonds)
* Free radical reactions
* Ca as a 'charge mover'

And thus biology embeds self-excitation by frequency generation. Negatively polarized nuclei can become such quantum radio frequency oscillators or RASERS.

Macroscopic quantum phenomena includes, besides coherent radiation, liquid helium and super conductivity. Effects analogous to the Josephson effect in superconductivity have at last been discovered in liquid helium, but these effects predicted in biological membranes at least since 1973 (J P Marton Physiol. Chem and Physics 5 259-270), have not been seen.

My prediction here, is that quantum mechanical properties of membranes (etc) are important in microgravity. Marton showed that membranes grow and divide so they maintain the lowest free energy and proposed that the Earth's magnetic field could lead to two forms of growth depending on its field strength. Analogously, I will propose that in microgravity a change in long range electron correlation exists due to adjustment to this new environment and via water structure, thiols, free radicals and certain charge movers, biological effects can appear if the magnetic moments induced exceed losses in the new circuit. (This is not related to the changes in the external fluid environment or to feedback controls in organisms such as swimming activity, which seems to be the most likely explanation for the changes noted in Paramecium flown in space.)

GRAVITY IN PHYSICS

Gravity and its relation to matter in the universe is one of the most daunting intellectual problems of modern physics. In Gauge theories, gravity is introduced in the form of supersymmetry leading to the existence of massive gravitinos, partners of gravitons, as the manifestation of gravity. Gauge field theory includes quantum chromodynamics, QCD (the strong interaction), and quantum flavourdynamics, QFD (synthesis of electromagnetic and weak forces) combined into various forms of Grand Unified Theory - GUT (QCD + QFD). These GUTs provide a framework for unifying three of the four known forces, and many GUT models have been constructed. For the moment, Kaluza-Klein theories seem to be favoured as the framework in which gravity can be unified with the three forces. This framework starts from a suitable higher dimensional theory of gravity (including Einstein's). This standard model of strong, weak and electromagnetic interactions usually requires precise adjustments of the scale of weak interactions in the order of 100 GeV, far below the scales of GUT (10^{15} GeV) and gravitation (10^{19} GeV). By relating particles of different spins, supersymmetric theories can escape this fine tuning. In these theories, gravity becomes responsible for the spontaneous breakdown of the electroweak and the grand unified gauge symmetries. If our world is indeed supersymmetric there will be many new particles to discover such as spin zero quarks. The dark matter of the universe could be "photinos" not electron neutrinos, and naturally the phase transition pattern in the early universe would be different from that found in non-supersymmetric theories.

Ephraim Fischbach, University of Washington, has put forward a more detailed proposal for a force which is a modification of the normal gravity force, and which, in practice, is only detectable at the scale of 200 metres. Three forms of data form the experimental base for Fischbach's so called "fifth force". They are:

1) The energy dependence of interactions involving the particle Kaon and its antiparticle.

2) Geophysical data of gravity on the Earth at different positions

3) Reassessment of Roland Eotvos' experiment to show that in fact, a composition dependent effect exists and that the gravitational force DOES NOT ACT EQUALLY, INDEPENDENT OF THE COMPOSITION.

Details of this experiment were discussed at the 11th International Conference on General Relativity in Stockholm, in 1986. (In fact two further days were spent on it!).

Here, we need concern ourselves only with the reassessment of the measurements by Eotvos as presented by Fischback et al [1].

Eotvos data has errors - of the order of 1 part per 10,000 - but are they systematic?

Fischback et al claims that they are, and further, that they are based on the baryon content (in this case, the nucleon content). S. Y. Chu and R.H. Dicke have put forward the idea that the systematic errors are due to thermal convection [2]. It is hard to assess this with the present data. A series of experiments is underway, the results of which will be needed before including a new short-range force. One thing is clear, that, gravity measurement is back in physics! (for example the gravitational constant is still uncertain to about 1 part in 5,000).

Gravitational physics ought to be fundamental in the development of any general model of microgravity. Newton's inverse square law of gravitation is well verified for astronomical distances. Supergravity theories suggest that Newton's law fails at distances of the order of metres, and there is conflicting experimental evidence on the validity of the inverse square law at these short distances. All periodic phenomena in gravitational fields (atoms, molecules, physiology, etc.) are basically a function of the field strength (i.e. potential) at the specific point under investigation. Because of this lack of a direct understanding of gravity, we have to develop methods that will allow us to measure changes in the processes of living matter as a function of time in microgravity.

The effects of gravity

A Newtonian gravitational field can, by a number of effects, shift the electrochemical potential. For example, the gravitational force on electrons must be balanced by an electrostatic force giving rise to an electric field (the Schiff-Barnhill field). An electric field can also result from a shift in the Fermi level, induced by lattice distortion due to the gravitational force on the ions. These gravitational effects can be 10 to 15 orders of magnitude greater than the relativistic shift in potential difference. The relativistic effect of a gravitational field can be detected in metals' electro-chemical potential μ if the latter is not a constant. The related quantity $\bar{\mu} = \mu(1 + \lambda)$ is the constant along the wire. In this the gravito-electrochemical potential is $\lambda = 2g/c^2$ and thus depends on the gravitational potential through the height z (g is the gravitational acceleration at the Earth's surface and c the speed of light in vacuum).

This gives:

$$\lambda/z \;=\; 1.09 \times 10^{16}/m$$

In a dissipation free metal, such as a super conductor, $\tilde{\mu}$ should be independent of position, even with a dc current flowing; as assessed by two observers of EMF=V, separated by z in height, this means that a circuit with two identical batteries connected in opposition by superconducting wires would have a net EMF $= \Delta v = \lambda v$ around the zero resistance loop leading to a loop current increasing linearly in time.

Experiments to compare the fractional change with height of the electrochemical potential difference between two superconducting wires to the fractional change in photon frequency over the same height (the last given by $\Delta v/v = \lambda$) have been reported by A. K. Jain. [3]

In this context it should be remembered that living systems do show some solid state processes such as:-

1. Conduction over energy barriers (tunneling)
2. Superconducting property
3. Piezoelectric property
4. Transmission of Infra-Red energy in lipid bi-layers

These could be of special importance, since the purely Newtonian gravitational field does not contribute to the net EMF.

The concept that the mass of an object is a function of its temperature and of its surroundings is a very old one.

Recently, John F. Donoghue and Barry R. Holstein have claimed that it is only the inertial mass (Newtons second law of motion) that varies with temperature and not the gravitational mass (Newtons law of gravitation). Further they claim that the expression for the energy of the system, known in dynamics as the Hamiltonian (see Davydov Model for Energy Transfer In Proteins), represents what in thermodynamics is free energy, and is to be identified with the inertial mass. [4]

The gravitational mass is derived from the energy momentum tensor in general relativity. The difference between the two energies or masses is in thermodynamics, i.e. the product of the temperature and entropy. Thus, the difference between gravitational and inertial mass will be the product of temperature and the rate of change of inertial mass with temperature.

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GRAVITY

Research in gravity offer the prospect of generating "breakthrough'or "Leapfrogging" capabilities. Thus, major technology advances will enable significant increases in the amount of power that can be obtained from a given mass in the future.

Identification of new approaches to gravity are revolutionary rather than evolutionary. This is sometimes called "breakthrough physics" and monitoring of such research has been a sustained effort at the United States Air Force Astronautics Laboratory.

Current efforts include an investigation of the Biefield Brown effect down to a vacuum of 1 microtorr and a voltage above 50 KV.

USSR

From the 1930 and 1940's work in the USSR have shown a continuing trend toward non-Einsteinian five dimensional theories. Indications are that the scientists are considering the fifth dimension to be physically real rather than a mathematical variable. This field could be a scalar field and several labs in the USA are designing approaches to experiment. At present no one in the USA to my knowledge is considering Prigogine crystals as a tool.

Prigogine Crystals

Prigogine crystals consists of an amorphous pellet made by sintering finely divided material at high temperature and pressure in such a way that the crystal is not in thermodynamic equilibrium. One material must be piezo-electric, the other radioactive. With proper internal stress each grain becomes a scalar interferometer and a one -way gate valve in electron flow.

Scalar waves which are longitudinal (like sound) as contrasted with electro-magnetic waves that are transverse and can penetrate a standard Faraday cage, while transverse waves cannot.

Quartz and germanium has been used in the past with different radioactive elements. I would suggest that since the primarily interacting source of scalar fields are at least a 5 dimension electrodynamics a Prigogine crystal is engineered to test the USSR gravity approach.

This issue is vital since interaction of virtual particles do not have to become exactly zero if such particles do have a gravitational interaction. The USSR physicist Ya B Zel'dovish demonstrated in the late 1960 that non vanishing energy density of the vacuum could emerge. A Prigogine crystal would act similar

to experiments aimed at costructing a "axion-radio"(steady magneticfield build up to convert an axion in a tuned microwave cavity into a photon) now attempted. Due to low intensity the quadrupole emission associated with molecular rotation and vibration of gravitational radiation is not likely to visualise the interaction. However, particle transformations especially e^-e^+ and p^-p^+ annihilation has been studied in the USSR as a microscopic processes giving off gravitational radiation. Especially D Ivanenko and A Sokolov worked on this problem based on quantum theory of fields.

It is possible that decay could be another way of study assuming that there is a slightly different rate of decay in free fall compared with that in Earth gravity. This would be a non first order effect and could together with the Prigogine crystal be developed into an important instrument.

A group in Moscow is finally working on self-generating plasmas and claims to have effects (6%) on the rate of Beta decay.

Heaviside's linearised Gravitational Theory

"As above, so below; but after another manner", is an old folk law. Perhaps we are more familiar these days with the phrase "Nature repeats itself". Certainly Nature does appear to have had only a limited number of tricks at its disposal during the Creation. But it has managed to conceal this fact from us by disguising natural phenomena to such an extent that outwardly they all appear quite different. However, the mathematician, by stripping away the outer covering and exposing the inner skeletal framework is able to classify phenomena on the basis of their mathematical structure.

The use of analogy can be a powerful tool in the hands of scientists. Not only does it aid the mind when trying to visualise what might be, but if an analogy is truly applicable an existing mathematical model can be interpreted in a new guise. Naturally there are pitfalls in applying an analogy and it is likely that some predicted result(s) will not occur. However, this does not necessarily invalidate the whole model. The reason for it must be sought and the pit avoided. So a new theory develops.

Among the many great scientists who utilised analogies were men like Oersted, Laplace, Faraday, Helmholtz and Maxwell, to name but a few. Indeed for Faraday, who was not a mathematician, analogy was the principle guide in his brilliant explorations of the unknown.

At this Round Table Conference we are particularly interested in any real physical links between electromagnetism and gravitation. Theoretically these subjects are linked, via Potential theory, with heat flow and fluid mechanics. Historically these four subjects are intertwined and often development in one area has led to development of its analogue.

It was Helmholtz who originally pointed out that electromagnetism is an analogue of Vortex theory in fluid mechanics. The analogy was utilised by Kelvin and Maxwell, the latter in his mathematical interpretation of Faraday's work on electromagnetism.

Maxwell's treatise was, however, rather obscure being written in terms of Hamilton's quaternions. It was Heaviside who simplified the approach and gave us today's familiar vector form of electromagnetic theory, whilst still retaining Hamilton's ∇ operator.

Using an electromagnetic analogy, Maxwell tried to extend the Newtonian potential theory of gravitation to incorporate dynamic effects. However, because he was unhappy with the concept of negative gravitational energy being stored in the Ether, he did not pursue this idea very far. Heaviside further developed the analogy (Slide 1). Following Maxwell's lead in introducing a displacement current (Slide 2), Heaviside introduced a dual of the gravitational field. At any point, the intensity of this new field $\underline{\mathcal{H}}$ has dimension of an angular momentum density (Slide 3). Integrating this field over a finite volume of space gives an angular momentum, which suggests that $\underline{\mathcal{H}}$ may be connected with Planck's constant $\hbar$. Perhaps there is a link here between continuous field theory and discrete quantum theory.

If one assumes that sources ($\mathcal{B}$) in the new field obey an inverse square law (Slide 4) then a new universal constant (p) arises. Stretching the analogy still further, one can imagine that an induced field ($\underline{\mathcal{B}}$) can be set up, analogous to an induced magnetic field, with an inertial permeability factor ($\frac{1}{p}$).

If one examines the self-energy in the gravitational field, one is confronted by infinities. However, by introducing a limiting process (renormalisation?) these can be avoided (Slide 5). This suggests that $Gp = c^2$, where G is the gravitational constant. One is left wondering what is the connection with $\frac{1}{\varepsilon\mu} = c^2$?

One immediate consequence of the above relationship between G and p is that the free space inertial permeablity is found to be 0.74×10^{-30} mg^{-1}, which explains one reason by $\underline{\mathcal{B}}$ fields have never been detected.

Naturally the analogy predicts the existence of gravitational waves (Slide 6).

Heaviside's method hardly saw the light of day, being discarded in favour of Einstein's geometrical theory of space-time. After remaining dormant for nearly a century, Heaviside's gravitational theory was recently revived (ref. 1). One of its values is that it offers engineers a relatively simple model of gravitational theory, which has a sense of familiarity about it.

For weak gravitational fields, Heaviside's method is seen to be a linearised, flat space-time, approximation to General Relativity, although there are some unexplained scale factor differences (Slide 7). It would appear that the gravitomagnetic field, predicted by General Relativity for weak gravitational fields, is very closely linked with Heaviside's $\underline{\mathcal{B}}$ field. Heaviside's method shows that Lense-Thirring precession is related to the Coriolis force, and is directly analogous to Larmour Precession in electromagnetic theory.

One interesting problem to investigate, using Heaviside's method, is the energy of a rotating mass ring. The mass current is given by $I_{mass} = \frac{1}{2\pi} M\omega$

where M is the mass of the ring and ω its angular velocity. The energy U_{self} stored in the Ether (Vacuum?, Space?) is, by analogy $\frac{1}{2}\iint_{S_{enc}} \underline{\mathcal{B}}_{self} \cdot dS$

Should this be equal to $\frac{1}{2}\mathbb{I}\omega^2$, where $\mathbb{I}$ is the moment of inertia of the ring?

Ref 1. D D Cattani Linear Equations for the Gravitational Field
Il Nuovo Cimento, Vol. 60B, No. 1, P67, Nov 1980

A GRAVITATIONAL AND ELECTROMAGNETIC ANALOGY.

Now, bearing in mind the successful manner in which Maxwell's localisation of electric and magnetic energy in his ether lends itself to theoretical reasoning, the suggestion is very natural that we should attempt to localise gravitational energy in a similar manner, its density to depend upon the square of the intensity of the force, especially because the law of the inverse squares is involved throughout.

Now what is there analogous to magnetic force in the gravitational case ? And if it have its analogue what is there to correspond with electric current ? At first glance it might seem that the whole of the magnetic side of electromagnetism was absent in the gravitational analogy. But this is not true.

Oliver Heaviside
'Electromagnetic Theory'
1893.

Extending Newtonian Gravitational Theory

$$\nabla . \underline{g} = -4\pi\rho G \qquad \text{(Poisson)}$$

$$\nabla . \underline{J} = -\frac{\partial \rho}{\partial t} \qquad \text{(continuity)}$$

Differentiating Poisson's eqn wrt time t and eliminating ρ

$$\nabla . \left\{ \underline{J} - \frac{1}{4\pi G} \frac{\partial \underline{g}}{\partial t} \right\} = 0$$

Since DivCurl = 0 always, Heaviside introduced $\underline{H}$ such that

$$\nabla \times \underline{H} = -4\pi \left\{ \underline{J} - \frac{1}{4\pi G} \frac{\partial \underline{g}}{\partial t} \right\} \qquad \text{(Maxwell's Displacement Current)}$$

SLIDE 2

The Heavisidian (or Gravito–magnetic ?) Field

Dimension of $\underline{\mathcal{H}} = M\,L^{-1}\,T^{-1}$

Suggesting intensity $\dfrac{\underline{\mathcal{H}}}{2\pi}$ is an angular momentum density.

For any volume V of space

$$\text{Angular Momentum } \underline{H} = \frac{1}{2\pi}\int_V \underline{\mathcal{H}}\, dV$$

Does the $\underline{\mathcal{H}}$ –field exist ? Is it related to Planck's constant h ?

SLIDE 3

Inertial Permeability

Dimensions of mono–pole $\beta = L^2 T^{-1}$

Assume Inverse Square Law

$$\underline{F} = -p\frac{\beta_1 \beta_2 \hat{r}}{r^2} = \underline{\mathcal{H}}_1 \beta_2 \quad \text{where} \quad \underline{\mathcal{H}}_1 = -p\frac{\beta_1 \hat{r}}{r^2}$$

Dimensions of $p = \frac{M}{L}$

The induced field $\underline{\mathcal{B}}$ is

$$\underline{\mathcal{B}} = \frac{1}{p}\underline{\mathcal{H}}$$

where $\frac{1}{p}$ is called inertial permeability.

Dimensions of $\underline{\mathcal{B}} = \frac{1}{T}$ induced angular velocity ?

SLIDE 4

Finite Self Energy

For a discrete mass distribution

gravitational PE = $U = \sum_{i=1}^{n} m_i \phi_i$ where $\phi_i = \sum_{\substack{j=1 \\ j \neq i}}^{n} -G_{ij} \frac{m_j}{r_{ij}}$

To remove ∞ , we define self-energy as

$$U_{self} = \frac{1}{2} \lim_{r_{ij} \to 0} \left\{ m_i \left[-G_{ij} \left(\frac{m_j}{r_{ij}} \right) \right] \right\} = \frac{1}{2} m_i c^2 \qquad \text{(Einstein ?)}$$

which suggests

$$\lim_{r_{ij} \to 0} \left[G_{ij} \left(\frac{-m_j}{r_{ij}} \right) \right] = G . p = c^2$$

SLIDE 5

Propagational speed of a gravitational disturbance

Dimensions of G.p $= \dfrac{L^2}{T^2}$

We can show

$$\nabla^2 \underline{g} = \frac{1}{Gp} \frac{\partial^2 \underline{g}}{\partial t^2}$$

Suggesting

gravitational propagation speed = speed of light

In which case :–

Inertial permeability of free space $= 0.74 \times 10^{-30}$ m/g

Scale factor differences

The linearised theory leads to a flat space time model (ie No space curvature).

1. Maxwell type eqns are derived which are similar to those which arise from General Relativity for Weak Gravitational fields.

2. Lense – Thirring precession is predicted, analogous to Larmour precession in E/M theory.

3. Flux of gravitational energy from an oscillating quadrupole is predicted.

A New Model of the Electron

Professor Roger Jennison began his presentation by reminding us of de Broglie's idea about the wave nature of matter (note attached) and how this led to the model of the free electron as a wave-packet. Roger pointed out that whereas the basic de Broglie approach was relativistic, the extension developed by Schrödinger was not. It was Dirac, in 1932, who re-cast the work to satisfy the requirements of relativity and one of the 'fall-outs' for doing this was electron spin. Thus electron spin may be treated as a relativistic effect. Another 'fall-out' from Dirac's work was negative electron energies, which eventually led to the discovery of the positron, by Anderson, in 1936. While investigating the effects of Cosmic Rays, Anderson observed that incoming photons, with enormous energy, were transmuting into pairs of electrons and positrons.

It is well known that de Broglie was not entirely happy with the development of Quantum Mechanics theory and he felt that there might be some hidden variables in classical mechanics (the Heavisidian field?) which, when uncovered, might explain quantum mechanical effects.

In an earlier paper (ref. 1), Professor Jennison has asked "Why are Newton's Laws laws?". By modelling the free electron as a phase-locked cavity, he was able to demonstrate that the reason a moving electron has inertia is due to a doppler effect suffered by the waves reflected from the cavity walls (ref. 2). Furthermore, his model shows that for a continuously applied force, these doppler effects form part of a discrete feedback signal which give rise to a quantum version of Newton's 2nd law, with Einstein's energy equation, $E = mc^2$, being a by-product of the theory.

Professor Jennison concluded his talk with a description of a new relativistic model of the electron, details of which are given in the attached paper.

References

1. R C Jennison — Why are Newton's Laws laws? Vistas of Astronomy, Vol. 30, p255-267, 1987

2. R C Jennison — What is an electron? Wireless World, P42-47, June 1979

De Broglie versus Schrödinger Wave Mechanics

De Broglie conceived the original idea of the wave nature of matter. This basic idea was very simple. He noticed that one could write energy as $E = mc^2$ and also as $E = h\nu$, both of which are relationships due to Einstein. De Broglie equated the two energies, thereby obtaining $h\nu = mc^2$ which can be rewritten as $c/\nu = h/mc$ but c/ν has the dimensions of a wavelength, λ, therefore $\lambda = h/mc$ where m is the total relativistic mass and mc is the relativistic momentum.

A year or two later, Heisenberg conceived the more abstract formulation of quantum mechanics. Max Borne recognised that Heisenberg's ideas corresponded to the mathematical formulation of matrices and almost immediately it was found that many of the problems in particle physics could be accounted within the matrix formulation. However the matrix mechanics was primarily an abacus, or what we might now think of as a computer program which gave the right results but offered no fundamental explanation of why this was so. In the blaze of success of the matrix mechanics, Louis de Broglie's work was overshadowed. It did not quite agree with the original (non-relativistic) quantum mechanics and it produced no such plethora of immediate results. As we now know, de Broglie's elegant concept was really too good and ahead of its time but Schrödinger produced a variant of wave mechanics which proved to be entirely compatible with the quantum (or matrix) mechanical computations. Neither Schrödinger's wave mechanics nor Heisenberg's matrix mechanics was relativistic but a few years later Dirac produced his relativistic analysis which became the basis of most subsequent work and even Louis de Broglie, who, at the time, was vacilating between two different interpretations of his mechanics (the pilot wave versus the double solution), surrendered to the popular view. The extraordinary fact is that de Broglie's original mechanics, unlike that of Schrödinger, was rigorously relativistic from the outset.

In 1952, de Broglie returned to his original mechanics, convinced that, after all, his first simple ideas were correct

and that "vibrations" should be associated with elementary particles of matter even when at rest. He was further convinced that there should be two solutions, An internal solution which described the particle itself and an external solution which described the way it interacted with other particles or the environment in general. The latter was similar to a relativistic form of Schrödinger's wave mechanics but the former had no equal, it implied a truly wave structure to fundamental matter itself. De Broglie realised that the internal solution would have to be non-linear but, despite the most valliant efforts he was never able to find the solution which he was so certain had to exist.

De Broglie waves and Shrödinger waves may be compared in the following table:

	frequency	phase velocity	wavelength
De Broglie	$\frac{1}{h}\cdot\frac{m_0c^2}{(1-v^2/c^2)^{\frac{1}{2}}}$	$\frac{c^2}{v}$	$\frac{c^2}{v}\cdot\frac{h(1-v^2/c^2)^{\frac{1}{2}}}{m_0c^2} = \frac{h}{mv}$
Schrödinger	$\frac{1}{h}\cdot\frac{mv^2}{2} = \frac{m_0c^2}{h(1-v^2/c^2)^{\frac{1}{2}}} - \frac{m_0c^2}{h}$	$\frac{v}{2}$	$\frac{v}{2}\cdot\frac{h}{\frac{1}{2}mv^2} = \frac{h}{mv}$

At first sight it may seem that Schrödinger's formulation is much simpler but if you look at it carefully you will see that there is something missing. The frequency term only uses the kinetic energy of the particle whereas the de Broglie expression uses the total energy, that is the sum of the kinetic and rest energies of the particle. If the particle is at rest, de Broglie's expression shows that it should still have a frequency of vibration $f = m_0c^2/h$ whereas Schrödinger's expression gives a frequency of zero. Certainly the particle still has its rest mass and so if matter waves are to have any real meaning it appears that de Broglie's interpretation is correct and Schrödinger's is in error. This is indeed so. The de Broglie treatment is rigorously relativistic from the outset whereas Schrodinger's is not and it has to be doctored to make it comply with relativity.

L. Mackinnon (Foundations of Physics, 11, 907-912, 1981) has shown very convincingly that electron interference and diffraction patterns cannot be explained by Schrödinger waves but they can be explained by de Broglie phase waves. It is remarkable that something as fundamental to electronics as this is seldom taught in our institutions.

R. C. Jennison

A NEW CLASSICAL RELATIVISTIC MODEL OF THE ELECTRON

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An electromagnetic model of the electron is derived from the application of rotational relativity to the trapping of an electromagnetic wave at the Compton frequency. This results in a spinning entity having the major properties of the electron. The electric field distribution is isotropic and varies as $1/r^2$ from the centre to infinity and there is a magnetic field aligned along the spin axis. The vector potential does not vary with distance from the centre but, when sampled by a relatively moving observer, it exhibits a wavelength inversely proportional to the relativistic momentum.

1. Introduction

It has been noted by Beil [1] that the properties of retarded null surfaces in space–time may be related to the structure of fundamental particles. In particular, Jennison et al. [2], in an earlier paper, combined this principle with phase-locking to derive a class of fundamental relativistically rigid proper clocks.

The approach used in this paper follows from the recent discovery that a set of identical helical null lines which are all contiguous with an axis of proper time may be arranged in such a manner that they form a unique and finite helicoidal surface in space-time [3]. This implies that any diameter of a physically rotating body may be constructed from a set of elementary primary waves. The remarkable geometry of the system is such that a cosinusoidal wave function extending from $-\pi/2$ to $\pi/2$ and corresponding to a phase-locked travelling wave, is in perfect balance with the relativistic enhancement of the outer parts of the system. An earlier paper [4] gave an account of phase-locking in this context. Standing waves were considered in that paper but the treatment is essentially equivalent when the component travelling waves are separated by rotation so that interference occurs only with coherent clones of the travelling wave system, thus producing a group wave system about the origin, as in the present case. In more recent papers [2,3,5] I attempted to identify the wave system with the de Broglie waves of Mackinnon's solution [6]. This association was incorrect and the relevant sections are respectfully withdrawn, although the major part of ref. [2] is still correct. An electromagnetic analysis is applied in this paper to achieve a coherent wave model of the electron, this differs in many respects from other very recent models such as that discussed by Barut [7].

2. A unique construction in space–time

Helical null lines are helices in space–time which satisfy the equation $dx^2+dy^2+dz^2=c^2\,dt^2$. The helicoidal surface (fig. 1) is the group formed from the intersection of a complete set of helical null lines contiguous with an axis of proper time and having a spatial orientation which is coherently related to the periodicity. The period of the helicoid is twice that of the individual helices. The surface is unique and has the parametric equations

$$x=\sin\nu+\sin\gamma,\quad y=\cos\nu+\cos\gamma,$$
$$-\infty<\nu<\infty,\quad 0<\gamma<2\pi. \tag{1}$$

Whence, on elimination of ν and γ, one obtains the equation of the helicoid

$$\tan(t/2)=x/y.$$

A suggested experiment to search for a link between electromagnetism and gravity

One of the original aims of the Round Table Meeting was to initiate and discuss speculative experiments which might reveal a link between electromagnetism and gravity.

Professor Jennison suggested the possibility of a connection between the gravitational constant G, the permittivity ε and permeability μ. This is not a new idea, indeed in 1920 Sir Oliver Lodge (ref. 1) stated:-

> "I am fully prepared, ..., to accept a gravitational influence on the Ether's dielectric constant, and, therefore on the square of its index of refraction".

However, Professor Jennison also gave the rough outline of an experiment, which he thought might be feasible, to investigate such a link. This would appear to be a step forward since, as far as we are aware, no previous experiments in this vein have been proposed.

Professor Jennison envisaged 3 air-gap capacitors being closely positioned next to the perimeter of a rotating disc containing two large, symmetrically placed, masses. Capacitance is dependent on the dielectric constant ε. The basis of the experiment would be to monitor the capacitance of each capacitor in order to ascertain whether there was any cyclic variation which could be attributable to the passing masses, and hence to G.

Immediately following the meeting, Professor Jennison revised his ideas and suggested a variation of his earlier experiment (ref. 2). Since his new ideas were partly sparked-off by the Round Table they are included here for wider dissemination.

His new apparatus is based on the principles of the earlier one, described above, but he claims that many orders of magnitude are recovered by using the gradient due to altitude of the earth's gravitational potential.

Quoting from his letter, "[The apparatus consists of] a metal tube, about a metre long, [mounted] on a horizontal axis through a point half way along the tube. At each end of the tube there is a 'rigid' vacuum capacitor and one looks for a [cyclic] change in the vacuum dielectric (corresponding to epsilon for free space in a gravitational environment), by a synchronous capacitor bridge technique as the system is slowly spun" (fig. 1).

His brief theoretical ideas are as follows:-

Suppose there is a relationship between G and c

Let $$\frac{GM}{r} = f(c^2) = c^2 - (c')^2$$

where $c' = \sqrt{c^2 - \frac{GM}{r}}$ is the velocity of light in that region according to the observation of a remote observer.

Note that if $\frac{GM}{r} = c^2$, ie if $r = \frac{GM}{c^2}$ then $c' \to 0$.

(This is the Schwarzschild radius).

Rewriting:-

$$\frac{GM}{r} = c^2 - (c')^2 = \frac{1}{\varepsilon_o \mu_o} - \frac{1}{\varepsilon' \mu'}$$

Professor Jennison suggests a maximum rotation rate of 1 rev/sec so that the rotational acceleration at a radius of 50cm is less than about 1g.

As shown in fig. 1 the position of each capacitor above the surface of the earth will vary cyclically by approximately 1 metre.

The difference in gravitational potential between the two capacitor positions is $\frac{GM_E}{r_1} - \frac{GM_E}{r_2}$. To first order, the maximum difference is $\frac{GM_E \ell}{R_E^2}$, where ℓ is the tube length.

As a fraction of the potential at the surface of the earth this is $\frac{\ell}{R_E}$, which is approximately 1.5×10^{-7}.

If the relationship between G and c holds then

$$\frac{GM_E}{r_1} - \frac{GM_E}{r_2} = \frac{1}{\varepsilon'_{r_2} \mu'_{r_2}} - \frac{1}{\varepsilon'_{r_1} \mu'_{r_1}}$$

To be able to detect any cyclical difference in the capacitance we must be able to measure more than one part in 10^8. Professor Jennison claims that this is within the realms of measurement by the synchronous capacity bridge.

Although Professor Jennison's experiment will need to be refined we do now have a feasible experiment to consider. Clearly there are a number of configurations one might want to test (eg. horizontal rotation, non-vacuum dielectrics, different tube lengths & so on), but are there any (theoretical?) reasons why it should not be pursued? BAe are considering funding this experiment.

<u>References</u>

1. O Lodge — Note on a possible structure for the Ether Phil. Mag., Vol. 39, 6th Series, No. 230, 1920

2. R C Jennison — Letter, enclosing details of "Revised experiment for the determination of ε_o in a gravitational environment". 5th April 1990.

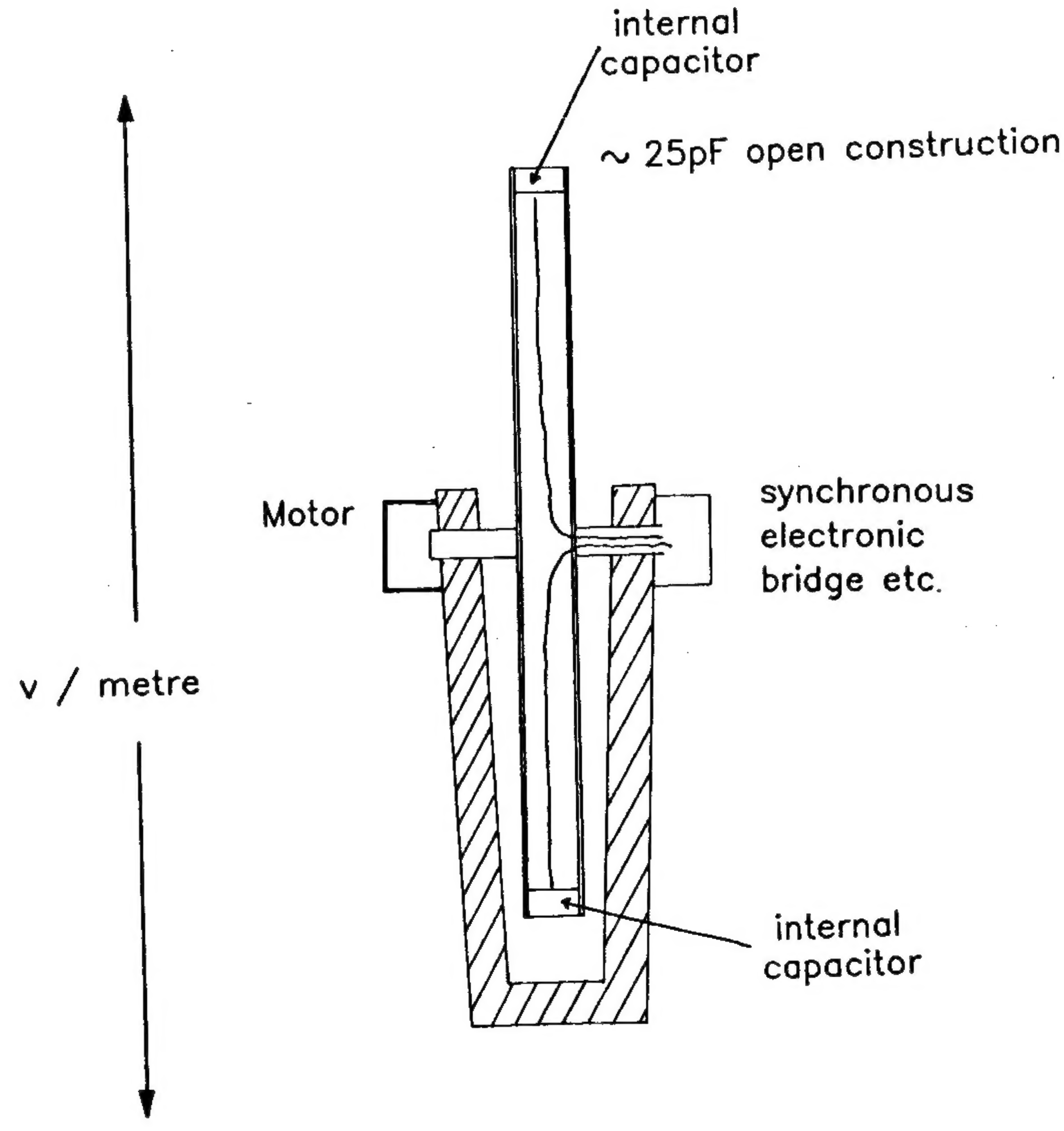

fig. 1 Professor Jennison's proposed experiment for the determination of $\mathcal{E}_0$ in a gravitational environment

An interaction between gravitational & electromagnetic waves

Unfortunately Dr A M Cruise had to withdraw from the Round Table discussions at the last moment in order to attend a meeting with Senior Soviet Scientists.

Mike had intended to discuss the possibility that the plane of polarisation of an electromagnetic wave is rotated by the presence of a gravitational wave (paper attached).

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An interaction between gravitational and electromagnetic waves

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Summary. A rotation of the plane of polarization of an electromagnetic wave results from the passage of the wave through a region with non-zero curvature tensor, as occurs when a gravitational wave is present. Although this effect is small when integrated over distances comparable to the wavelength of gravitational waves, there are plausible geometrical situations in which the effect is cumulative over long path lengths. In addition the interaction can take place close to the source of gravitational waves where the dimensionless wave amplitude can be large. The magnitude of the expected rotation is estimated for a few astronomical sources of gravitational waves.

1 Introduction

Gravitational waves are weak and very difficult to detect individually although there is mounting evidence for their emission from the binary pulsar, as the orbital parameters are observed to change. In contrast, electromagnetic waves from cosmic sources are easy to detect and many of their properties can be measured with high precision. These considerations have led many authors to discuss possible interactions between gravitational and electromagnetic waves in order to see if measurable changes in the latter can be used to indicate the presence of a gravitational wave. Three processes have previously been investigated. Gravitational waves traversing a light beam will cause fluctuations in the intensity and position of the beam as measured by an observer (Zipoy 1966; Bergmann 1971; Bertotti & Catenacci 1975). In principle this effect could be detected with point astronomical light sources or by fluctuations in the (assumed) isotropic microwave background (Dautcourt 1969) but in both cases the effect is extremely small (of the same order as the metric perturbation, h). Several processes combine to cause a frequency change in radio waves sent to and from distant spacecraft (Estabrook & Wahlquist 1975). Thirdly, the passage of a gravitational wave through a high Q electromagnetic cavity might be detected by a frequency change in the standing electromagnetic wave (Braginsky & Menskii 1971).

All these effects are very small for gravitational waves with amplitudes in the expected range of $10^{-24} < h < 10^{-14}$ (Thorne & Braginsky 1976; Press & Thorne 1972) but there is an interaction between a gravitational wave and an electromagnetic wave which does not appear to have been explored in the literature. The angle of polarization of a light beam will

be rotated as it travels through regions of space with a non-zero curvature tensor. This process has been studied for situations in which the non-zero curvature results from the presence of static or rotating masses (Pineault & Roeder 1971; Leiter 1978; Balasz & Bertotti 1963) or from rotating rings of matter (Dehnen 1973). In many such cases the integrated effect along the photon path is zero due to the rate of rotation being anti-symmetric about some plane of symmetry in the interaction. Due to the equality of the velocities of electromagnetic and gravitational waves, it is possible to visualize interactions between the two in which the rotation of the plane of polarization does not integrate to zero along the photon path as will be shown in Section 3. There are two properties of this interaction which suggest that it might be used to detect individual gravitational waves. If the photon moves in a region of constant curvature then parallel propagation of the polarization vector will cause a monotonic change in the position angle of that vector so that although the rotation induced in one wavelength of the gravitational wave is small (of order h) the cumulative effect over long paths may be very much larger. Under appropriate circumstance the interaction can take place close to the source of the gravitational waves in a region where the metric perturbation caused by the wave has a large amplitude. Photons passing through this region simultaneously with the gravitational wave will have their plane of polarization rotated by an amount proportional to the *local* metric perturbations while those arriving before and after the gravitational wave will not.

These two properties serve to amplify the effect to an extent that may be observable. It is the purpose of this paper to estimate the degree of rotation that may occur in a geometrically simple interaction between gravitational and electromagnetic waves using several simplifying assumptions.

2 The interaction with parallel electromagnetic and gravitational waves

Let $\tilde{x} = (x^0, x^1, x^2, x^3)$ be the coordinates of an event in a Lorentz frame and let the wave vector of a plane gravitational wave be $\tilde{k} = (k_0, k_1, k_2, k_3)$. The phase of the gravitational wave at $\tilde{x}$ is given by $\phi = k \cdot \tilde{x} = k_\nu x^\nu$ using the usual summation convention.

In the weak-field approximation a plane gravitational wave can be represented by a metric perturbation $h^{\mu\nu}$ such that the metric tensor $g^{\mu\nu}$ is given by $g^{\mu\nu} = \eta^{\mu\nu} + h^{\mu\nu}$ where $\eta^{\mu\nu} = \mathrm{diag}(1, -1, -1, -1)$ is the metric tensor in a Lorentz frame.

$h^{\mu\nu}$ can be derived from the field equations assuming that $|h^{\mu\nu}| \ll 1$ to give a form for a plane wave

$$h^{\mu\nu} = Re\,[A^{\mu\nu} \exp(ik_\sigma x^\sigma)] = Re\,[A^{\mu\nu} \exp(i\phi)]$$

where $Re(F)$ is the real part of F.

Let $\tilde{\Pi} = (\Pi^0, \Pi^1, \Pi^2, \Pi^3)$ be the polarization vector of a photon. Since $\tilde{\Pi} \cdot \tilde{P} = 0$ where $\tilde{P}$ is the wave vector of the photon then $\Pi^0 = \Pi^2 = 0$ for a photon travelling along the x^2 axis and $(\Pi^1)^2 + (\Pi^3)^2 = 1$.

The polarization vector of a photon propagates by parallel transport in the geometric optics approximation. This simplifying assumption is valid when the reduced wavelength of the photon $\lambda\mathrm{opt}/2\pi$ satisfies two conditions, namely

$$\frac{\lambda\mathrm{opt}}{2\pi} \ll \text{radius of curvature of the wavefront}$$

and

$$\frac{\lambda\mathrm{opt}}{2\pi} \ll (\text{Riemannian})^{-1/2}$$